

**STATE OF FLORIDA
DEPARTMENT OF NATURAL RESOURCES**

BUREAU OF GEOLOGY
Robert O. Vernon, Chief

REPORT OF INVESTIGATION NO. 56

**GENERAL HYDROLOGY
OF THE
MIDDLE GULF AREA, FLORIDA**

By
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U. S. Geological Survey

Prepared by the
U. S. GEOLOGICAL SURVEY
in cooperation with the
BUREAU OF GEOLOGY
DIVISION OF INTERIOR RESOURCES
FLORIDA DEPARTMENT OF NATURAL RESOURCES
and the
SOUTHWEST FLORIDA WATER MANAGEMENT DISTRICT

Tallahassee, Florida
1970

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LETTER OF TRANSMITTAL



Bureau of Geology
Tallahassee
April 14, 1970

Honorable Claude R. Kirk, Jr., *Chairman*
Florida Department of Natural Resources
Tallahassee, Florida

Dear Governor Kirk:

The Bureau of Geology, Department of Natural Resources, is publishing as Report of Investigation No. 56, a report on the "General Hydrology of the Middle Gulf Area, Florida" prepared by the U.S. Geological Survey in cooperation with the Bureau of Geology and the Southwest Florida Water Management District.

The area covered in this report is one of the metropolitan centers in the State. Its growth is intimately tied in to the occurrence and availability of adequate potable water. The 2½ year study has provided many hydrologic aspects of the area that will aid in the formulation of water-control designs and water-management practices.

The findings of the investigation are contained in two separate reports. This report contains an evaluation of the general hydrology of the entire Middle Gulf area, and includes both a water balance analysis, and a description of the movement and chemical character of the water. An earlier report by J. W. Stewart, U. S. Geological Survey, evaluated the effects of pumpage in northwest Hillsborough and northeast Pinellas counties.

Respectfully yours,

Robert O. Vernon, *Chief*

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GENERAL HYDROLOGY OF THE MIDDLE GULF AREA, FLORIDA

By

R. N. Cherry, J. W. Stewart, and J. A. Mann

ABSTRACT

The Middle Gulf area is in the west-central coast of peninsular Florida and encompasses about 1,700 square miles. It contains the cities of Tampa, St. Petersburg, Clearwater, Brooksville, and Crystal River. The area is drained principally by seven streams, Crystal, Homosassa, Chassahowitzka, Weekiwachee, Pithlachascotee and Anclote Rivers and Cypress Creek. The average daily discharge from the area not including peninsular Pinellas County and some coastal areas, for the period January 1964 — June 1966, was 2,300 cfs (cubic feet per second), or about 1.5 bgd (billion gallons a day). The average daily discharge of Crystal River alone was 930 cfs (0.60 bgd), or nearly 40 percent of the total.

No permanent regional declines in surface or ground-water levels have occurred in the area. The greatest local declines, ranging from 6 to 14 feet, occurred in the area of the well fields in northwest Hillsborough and northeast Pinellas counties.

The Middle Gulf area is part of a large hydrologic system. The total system encompasses an area of about 3,500 square miles and extends to the eastern topographic divide of the Withlacoochee River. The source of water for the system is rainfall which averages about 55 inches annually. Principal outflow from the system is evapotranspiration which amounts to about 67 percent of the total outflow. Runoff amounts to about 32 percent and ground-water outflow about 1 percent.

The Middle Gulf area is in the downgradient part of the larger Middle Gulf hydrologic system and most of the streamflow and ground-water outflow from the hydrologic system discharges from the Middle Gulf area. During a near average period, June 1964 — May 1966, precipitation on the Middle Gulf area was 114 inches; ground-water inflow, 24 inches; evapotranspiration, 77 inches; runoff, 59 inches; and ground-water outflow, 2 inches.

Most of the runoff from the area is discharged either as springflow or seepage to streams from the Floridan aquifer. Eighty percent of the annual streamflow from the area is water derived from the Floridan aquifer.

The water-level gradients in the system are about the same as the topographic gradients (2-3 feet per mile). Water levels in all lakes, streams, and aquifers within any one area fluctuate through about the same range, but the fluctuations are greatest in the upgradient areas.

Water levels are highest in the late summer or early fall following the rainy season and are lowest in late May or early June. Inflow to the system occurs primarily from June to September.

The change in storage from periods of high water level in late summer to low water level in late May is equivalent to about 8 inches of water over the Middle Gulf area.

Tide has a pronounced effect on the outflow from the areas. During periods of high tides, outflow is diminished and during periods of low tides outflow is increased.

The chemical quality of ground and surface water is good. The mineral content is generally less than 500 mg/l (milligrams per liter) in the ground water and 20 mg/l in the surface water except near the coast, where the mineral content of both surface and ground water may approach or be the same as that of sea water.

Ample supplies of good quality water are available for existing and foreseeable uses. The present (1969) problem is one of water management and optimum development rather than the availability of water. By properly spacing wells, avoiding excessive pumping rates in localized areas and distributing well fields over wide areas, drawdowns between wells and between respective well fields would be minimized. Overdevelopment and subsequent declines in water levels, now reflected to some degree in lowered lake levels and in reduction in streamflow, would be decreased. Implementation of measures noted would tend to minimize conflicts of interest between various water users throughout the area.

INTRODUCTION PURPOSE AND SCOPE

The growth and economy of the Middle Gulf area, figure 1, and its predicted expansion require ever-increasing quantities of water for a variety of uses which include domestic and public supplies, for agriculture and industry, for protection during droughts, for abatement of pollution and saltwater intrusion, for preservation of fish and wildlife,

or recreational and navigational needs, and for maintaining minimum low in the streams and desired levels in the many lakes in the area. Expansion has been from the Tampa — St. Petersburg area northward primarily along the coast into relatively undeveloped areas and is only a local phase of active expansion of the population and the economy of the state.

The water supplies to accommodate the anticipated increase in demand will be obtained mostly from the Floridan aquifer. Fresh water is available in some parts of the coastal areas at shallow depths, but in other coastal areas salt-water encroachment in the Floridan aquifer has limited the utility of the water.

In parts of the area pumpage from the Floridan aquifer has lowered some lake levels and reduced the flow of affected streams. Water that has previously been utilized for recreation is now being diverted to municipal or industrial use. The competition for water within the area has intensified in recent years and conflicts of interest have arisen.

Recognizing that an understanding of the water resource is prerequisite to efficient water management, the Southwest Florida Water Management District and the Bureau of Geology, Florida Division of Interior Resources, Department of Natural Resources, requested that the U. S. Geological Survey evaluate the potential water supply of the Middle Gulf area. In the course of evaluating the potential water supply, many hydrological aspects were investigated during the 2½ years of study which began January 1, 1964. These evaluations should aid in the formulation of water-control designs and water-management practices. Special emphasis was placed in the study on northwest Hillsborough and northeast Pinellas counties, where heavy demands have been placed on the water supply and where increasingly greater demands are expected to occur because this area is rapidly becoming urbanized.

The findings of the investigation are contained in two separate reports. This report contains an evaluation of the general hydrology of the entire Middle Gulf area, and includes both a water balance analysis, and a description of the movement and chemical character of the water. An earlier report by Stewart (1968) evaluated the effects of pumpage in northwest Hillsborough and northeast Pinellas counties.

PREVIOUS INVESTIGATIONS

References to the hydrology and geology of the Middle Gulf area have been made in several reports published by the Florida Geological

Survey and the U. S. Geological Survey. Ferguson and others (1947), as part of a state-wide inventory of the larger springs in Florida, described several of the large springs in the area. Heath and Smith (1954, p. 38-42) discussed the hydrology of Pinellas County and Taylor (1953) described the drainage of Lake Tarpon in detail and some of the springs and sinks in the vicinity of Lake Tarpon. Wetterhall made a geohydrologic reconnaissance of Pasco and southern Hernando counties (1964) and a reconnaissance of springs and sinks in the general area (1965). Parker and others (1955) named and described the Floridan aquifer. Cooke (1945) and Vernon (1951) described the geology of Florida, and Vernon (1964) described the geology of Citrus and Levy counties. Matson and Sanford's report (1913) on the geology and ground water of Florida has been particularly useful in this study. Their report has pertinent information on the area. Menke, Meredith and Wetterhall (1961) described the water resources of Hillsborough County.

The Florida Department of Water Resources made a reconnaissance of the hydrology of the Gulf Coast Basins in 1961, and in 1966 published a report entitled "Florida Land and Water Resources, Southwest Florida." The Florida Division of Water Resources and Conservation's Gazetteer of Florida Streams (1966) gives statistics pertaining to several streams in the area.

METHODS OF INVESTIGATION

To evaluate and understand the water resources of the area, the entire hydrologic environment were studied. Rainfall, streamflow, and lake and ground-water level data was collected during the study at sites shown in figure 1. Additional data on rainfall and temperatures were obtained from the U. S. Weather Bureau for six stations in the Middle Gulf hydrologic system outside of the Middle Gulf area.

Drainage characteristics of the area were determined by collecting daily streamflow and water-quality data, by making field and aerial reconnaissances, and by studying maps and aerial photographs.

A detailed field reconnaissance was made during May and June, 1964, of all known or probable sites of stream discharge from the hydrologic system. Specific conductance of the water was measured at these sites to determine if the water was fresh or salty. If the water was fresh — less than about 5,000 micromhos — and the flow was greater than about 5 cfs (cubic feet per second) or 3.2 mgd (million gallons per day), a streamflow measurement was made. Most streamflow measurements were not affected by Gulf tides. Continuous recorders were operated at sites on major streams, and periodic measurements were made at minor flow sites. The flow of streams for which only periodic

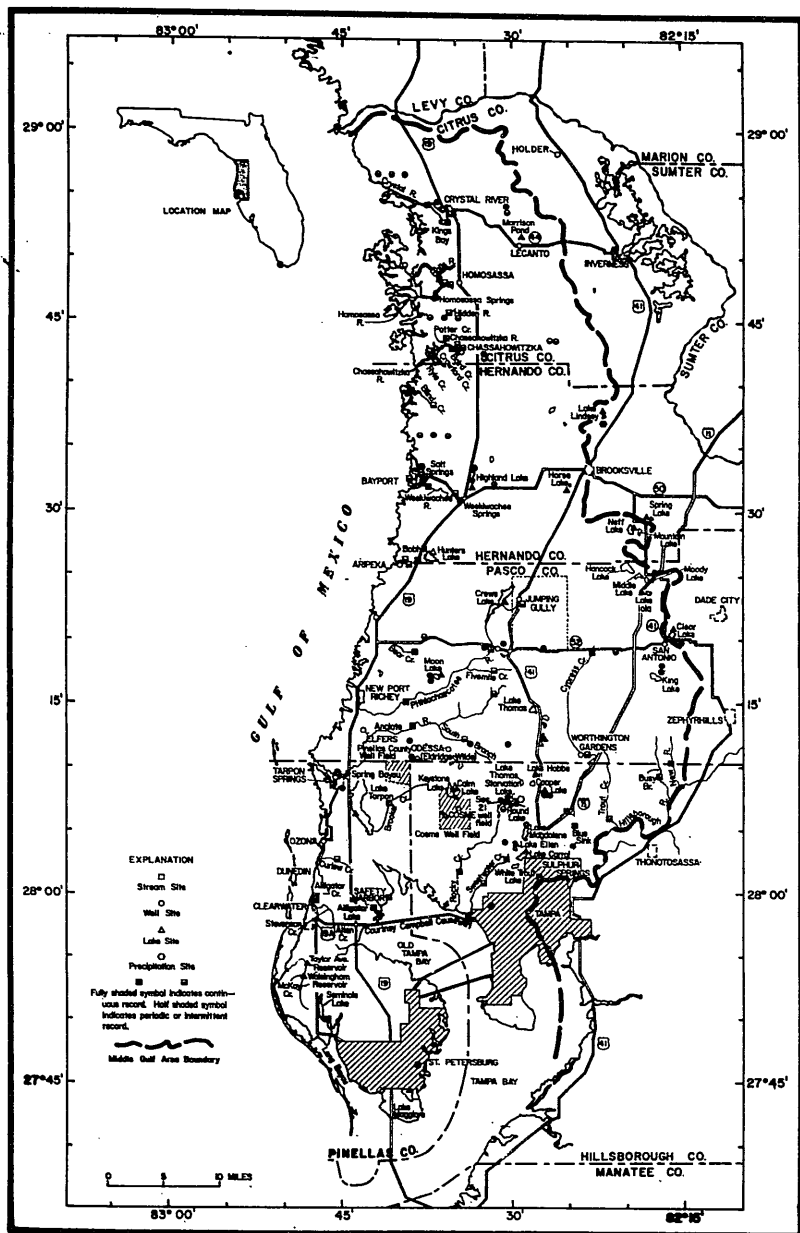


Figure 1. Map showing location and data-collection sites in and near the Middle Gulf area

measurements were available was computed by correlation with nearby continuous record stations.

Spring flow does not vary greatly within short periods, and monthly flow values were sufficient to compute the average flow. For example, monthly average flows determined from the monthly flow values of Rainbow Springs in Marion County are in close agreement with those determined from the daily flows. The flow for the period of study from large springs such as Weekiwachee, Chassahowitzka, and Homosassa were determined from hydrographs of monthly flow measurements. The flows of smaller springs, such as Bobhill and Salt in Hernando County, were measured about two to three times per year. The measurements were made at times of both high and low flow and were averaged to obtain the average flow for the period of study.

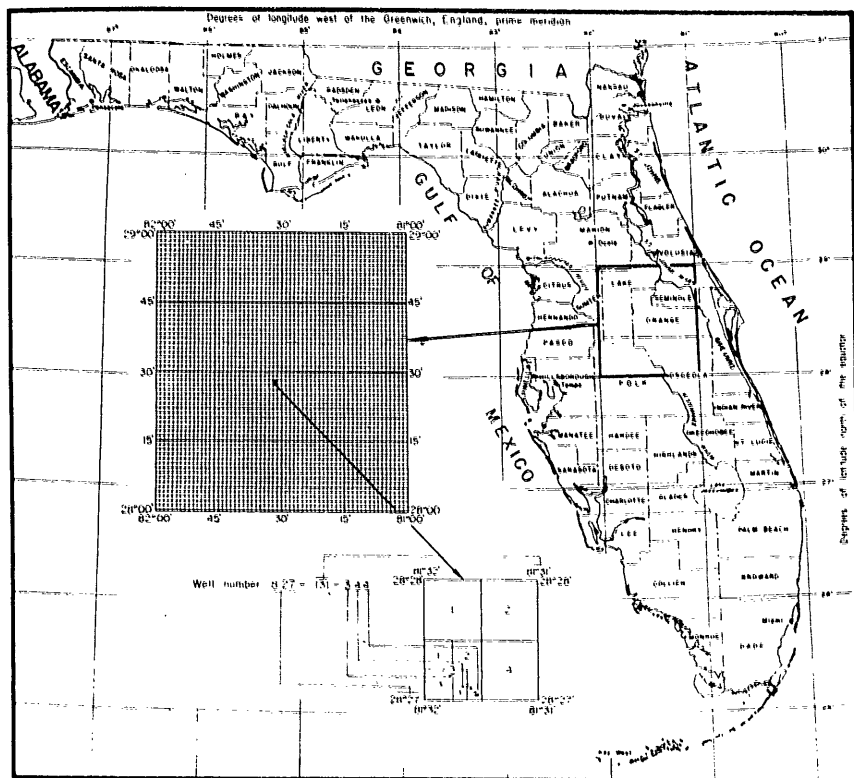
Occurrence and quality of ground water were determined by collecting data on water levels, surface and subsurface geology, and water samples for chemical analysis from springs and wells, most of which are supplied by the Floridan aquifer. Continuous records of water-level fluctuations in the aquifer were supplemented by periodic measurements of water levels in wells. The level of water in each well relative to mean sea level datum was determined from topographic maps or by a spirit level.

To obtain specific information on the occurrence of ground water in the Middle Gulf area, test wells were drilled. Additional subsurface information was obtained by interpretation of electric, gamma-ray, and drillers' logs of wells in the area. All well sites were numbered, based on coordinates of a state-wide grid of 1-minute parallels of latitude and 1-minute meridians of longitude as shown in figure 2.

ACKNOWLEDGMENTS

The writers wish to express their appreciation to the many citizens of the area who permitted the sampling of water and measuring of water levels in their wells and to the well drillers for furnishing drill cuttings, water-level data, and other helpful information. Special acknowledgments are due to the Florida State Road Department and the counties of Citrus, Hernando, Pasco, Hillsborough, and Pinellas for granting permission to drill test wells on public lands.

Special thanks are due to Drs. Luther C. Hammond, R. E. Caldwell and V. W. Carlisle of the University of Florida and their aid and suggestions in the determination of evapotranspiration by the Thornthwaite method.



Special thanks are also due to Dale Twachtmann, Executive Director, Southwest Florida Water Management District, for his patient encouragement throughout the investigation, and to Gerald G. Parker, Chief Hydrologist, of the same agency for his review of the manuscript.

Appreciation is expressed for the extensive technical and editorial review of the manuscript by J. S. Rosenshein, Eugene R. Hampton, Gilbert H. Hughes and C. A. Pascale, all of the U. S. Geological Survey.

The work on this project was done under the general direction of C. S. Conover, District Chief, Water Resources Division, U. S. Geological Survey.

GEOGRAPHY

LOCATION AND EXTENT OF AREA

The Middle Gulf area, about 1,700 square miles, is in the central west coast of peninsular Florida and includes parts of Citrus, Her-

nando, Pasco, and Hillsborough counties and all of Pinellas County (fig. 1). The area is bounded on the east and north by the western edge of the Withlacoochee drainage basin, on the south by the Hillsborough River and Tampa Bay, and on the west by the Gulf of Mexico. This area contains a number of major cities and towns which had the following population according to the 1960 census: Tampa, 288,000; St. Petersburg, 193,000; Clearwater, 37,000; Dunedin, 8,444; Tarpon Springs, 6,768; New Port Richey, 3,520; Brooksville, 3,301; and Crystal River, 1,423. Both the population and industry of the area are rapidly increasing and the demands for water accelerating. The Middle Gulf area is a part of the Middle Gulf hydrologic system, (figure 3). The system encompasses an area about 3,500 square miles and extends to the eastern topographic divide of the Withlacoochee River. The Middle Gulf area forms the downgradient part of the total water system.

CLIMATE

The climate is characterized by warm and relatively humid summers and mild relatively dry winters. The normal annual rainfall varies from about 51 to 58 inches, figure 4, and is unevenly distributed with more than half falling from June to September. Tropical storms in the summer and fall and occasionally in the winter bring intense rains to the area. The distribution of the normal annual rainfall in the Middle Gulf area is shown in figure 4.

Evaporation is greatest during May and June and in some years the evaporation in these two months accounts for nearly 25 percent of the annual total (Florida Board of Conservation 1966, p. 18).

Variations in day to day maximum temperatures during the summer range from about 72°F to 90°F and during the winter from about 55°F to 75°F. During the winter, occasional cold fronts move through the area that drop temperatures into the low and middle 20's.

TOPOGRAPHY AND DRAINAGE

Land elevations range from sea level at the shoreline or coastline to about 280 feet above msl (mean sea level) near Dade City. The areas of highest elevations are a series of eroded ridges that trend to the northwest and a ridge of poorly defined sand hills that parallels the gulf. These hilly areas occupy much of Citrus and Hernando counties and eastern Pasco and southern Pinellas counties. The western part of the Middle Gulf area between the Gulf and the sand hills, and the southern part of the area adjacent to Old Tampa Bay are characterized

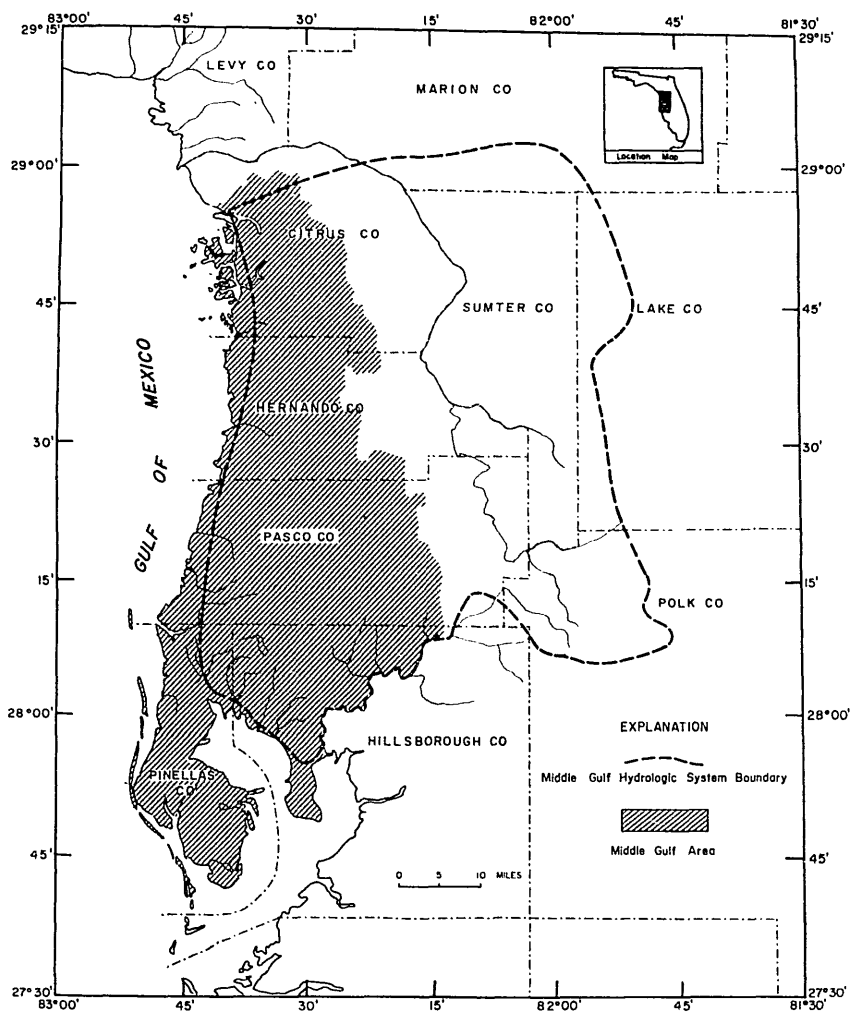


Figure 3. Map showing Middle Gulf hydrologic system boundary and Middle Gulf area

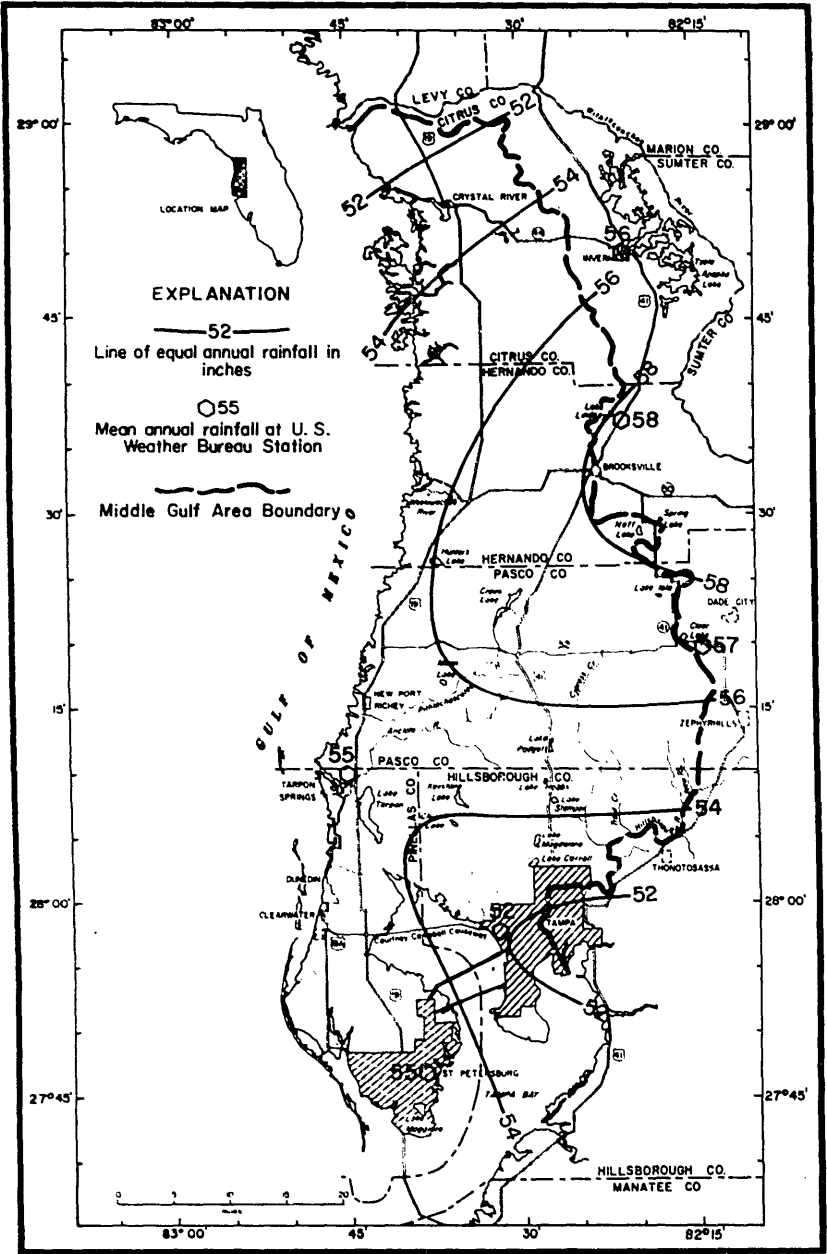


Figure 4. Map showing normal annual rainfall in Middle Gulf area 1931-1960

by relatively flat swampy lowlands, figure 5. These lowlands form a broad plain with gentle relief in the western parts of southern Pasco, Hillsborough, and northern Pinellas counties. In eastern Pasco and northeastern Hillsborough counties the land surface becomes gently rolling with smoothly rounded hills and shallow depressions.

The principal streams in the Middle Gulf area are Crystal, Homosassa, Chassahowitzka, Weekiwachee, Pithlachascotee, and Anclote rivers; and Rocky, Sweetwater, and Cypress creeks. Streams in the northern part generally originate at springs and carry little overland flow whereas streams in the southern part carry substantial overland flow.

The area contributing water to a stream is usually delineated by topographic divides. However, in the Middle Gulf area, the area contributing water to a stream may better be delineated by ground-water divides than by surface-water divides, because most of the larger streams are fed by ground water issuing from springs and seeps.

In Citrus and Hernando counties and northern Pasco county surface drainage is almost nonexistent. Sand hills and highly permeable land surfaces capture most of the precipitation that falls on them, and sinkholes capture a large part of the surface drainage.

Some of the sinks in the area that are known to be hydraulically connected to the Floridan aquifer and to transmit large quantities of water vertically are shown in figure 6. In the Brooksville area large volumes of water recharge the aquifer through sinks. Blue Sink, northeast of Brooksville, is capable of leaking large quantities of water underground. This sink has a drainage area of about 30 square miles. Numerous other sinks also occur in this area, including a large group of sinkholes in the prairie southwest of Brooksville. Some sinks, such as a sink in the southeast part of Neff Lake, have made prairies of former lake bottoms.

Pecks Sink near Brooksville accepts drainage from an area of more than 15 square miles and is one of a group of four or five sink complexes in the area. No flow into the sink was observed during the period of study. However, flow was observed during other periods. During extremely wet periods the overflow from Horse Lake drains into Pecks Sink.

The sinks in the Squirrel Prairie area southeast of Brooksville accept drainage from about 20 square miles in the upper reaches of the Pithlachascotee River. Crews Lake, which is southwest of Squirrel Prairie, is in the headwaters of the Pithlachascotee River. The lake has an active sink which drains about half the inflow to the lake (about 10 cfs, or 6.4 mgd).

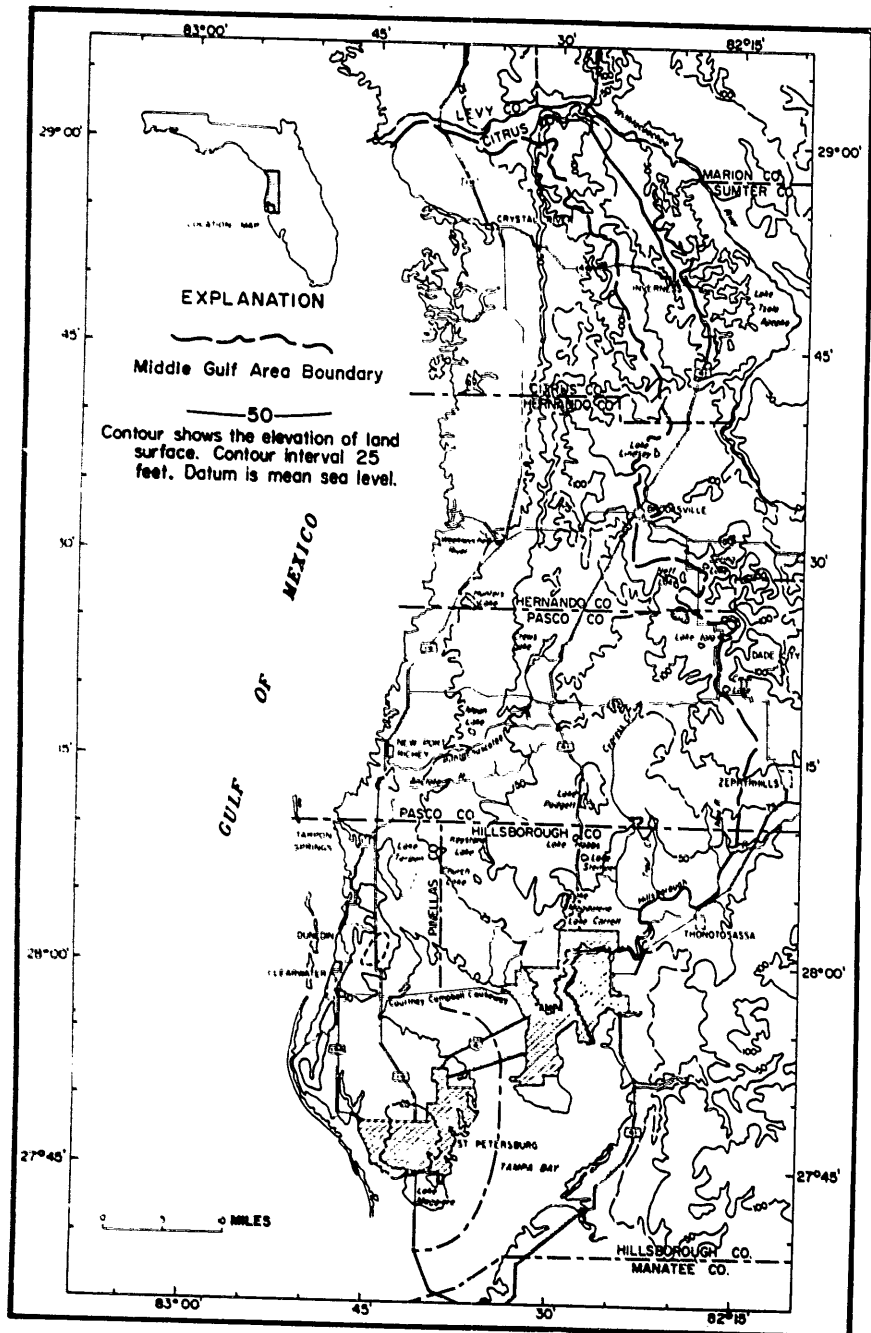


Figure 5. Map showing topography of the Middle Gulf area

The "Blue Sink" area of Sulphur Springs at the northern limits of Tampa and lying immediately west of U. S. Highway 41 receives much of the drainage from about 15 square miles. At least some of the flow into this sink complex emerges in Sulphur Springs, about 2 miles south of the Blue Sink area. The average flow into this sink complex during the study was less than a cubic foot per second (0.5 mgd). Maximum flow to the sinks for the period of record August 1945 — September 1950, August 1964 — June 1966, was about 100 cfs (65 mgd). Studies in this area in September 1945 indicated that this sink complex had a vertical drainage capacity of about 40 cfs (26 mgd). During periods of excessive rainfall when the intake capacity is exceeded, adjacent residential sections are flooded. The flow to the Bear Sink complex, about 7 miles northeast of New Port Richey, was measured as part of the study. The average inflow of Bear Creek was about 30 cfs (19 mgd) and the maximum inflow (March 1965 — June 1966) was 350 cfs (220 mgd) in August 1965. Maximum inflow during the period of study was probably about 600 cfs (388 mgd) in September 1964. This sink complex is in a sandhill area that has no surface drainage except the inflow channel.

GEOLOGY

The Middle Gulf area is underlain at depth by several hundred feet of solution-riddled limestone and dolomite that compose the following formations in ascending order: Lake City Limestone, Avon Park Limestone, the Ocala Group, Suwannee Limestone, Tampa Formation, and the Alachua and Hawthorn Formations. These formations¹ range in age from Eocene to Miocene.

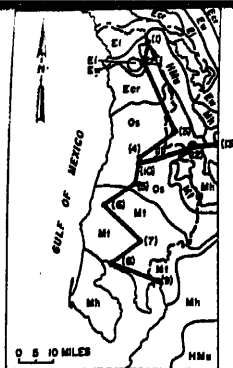
The solution-riddled and faulted limestone formations comprise the Floridan aquifer. This aquifer is the principal storage and water-conveying component of the hydrologic system in the Middle Gulf area. It is the source of nearly all ground-water supplies in the area.

The aquifer is overlain by sand, silt, and clay of varying thickness. The more permeable beds within the sand, silt, and clay unit form a subsurface reservoir called the shallow aquifer. Where clay is present, the downward water movement is retarded. The physical characteristics of the rock units underlying the area are summarized in figure 7 — the areal distribution of the Hawthorn Formation and older units beneath surficial deposits is shown.

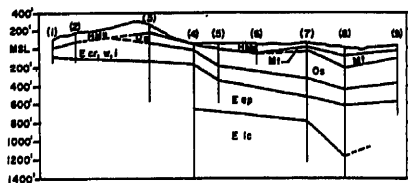
HYDROLOGY

The quantity and quality of water at a particular place may vary greatly from time to time. The changes may be rapid or very slow and

¹The nonmenclature used in this report conforms to that of the Bureau of Geology, Florida Division of Interior Resources, Department of Natural Resources, and not necessarily to that of the U.S. Geological Survey.

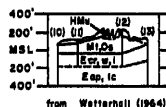


Map showing distribution geologic units of Miocene age and older
(adapted from Puri and Vernon, 1964)



EXPLANATION

- HM-Miocene age and younger
- M-Miocene age
- O-Oligocene age
- E-Eocene age
- u-undifferentiated
- h-Hawthorn Formation
- t-Tampa Formation
- s-Suwannee Limestone
- cr-Crystal River Formation
- w-Williston Formation
- i-Inglis Formation
- ap-Avon Park Limestone
- lc-Lake City Limestone
- Middle Gulf Area Boundary



from Waterhall (1964)

System	Series	Formation ^{1/}	Approximate thickness (ft.)	Lithology	Aquifer
Quaternary	Holocene (H)				
	Pleistocene (P)	Undifferentiated	2/		
Tertiary	Eocene (E)	Hawthorn ^{2/} Formation	0-90	Sand and shell; alternating with clay, blue-gray, and clay, gray-green sandy, calcareous, phosphatic; interbedded with layers of limestone, gray, white, and tan, sandy, phosphatic.	Shallow
		Tampa Formation ^{3/} (t)	100-150	Limestone, white to gray, sandy; locally crystalline; contains dolomitic and silicified layers.	
	Ocala Group	Suwannee Limestone (s)	0-300	Limestone, cream to tan, thin-bedded, fine-grained, dense, hard.	
		Crystal River Formation (cr)	0-300	Coquina, white to cream, soft, massive, with pasty calcite matrix.	Floridan
		Williston Formation (w)	30-50	Coquina, cream-colored, or limestone, cream to tan, detrital;--loosely cemented calcareous matrix; locally silicified.	
		Inglis Formation (i)	50-150	Limestone, cream to tan, granular, porous, medium-hard, massive; dolomite, locally tan to brown, near base.	
		Avon Park Limestone (ap)	50-500	Limestone, white to tan, soft, chalky, granular; dolomite, tan to brown, hard, crystalline.	
		Lake City Limestone (lc)	500-1000	Limestone, tan to cream, soft, granular, pasty; locally interbedded with layers of dolomite and bentonitic clay; some gypsum.	

- ^{1/} Nomenclature conforms to that of the Bureau of Geology, Florida Department of Natural Resources
- ^{2/} Designated surficial deposits in this report
- ^{3/} St. Marks Formation of Puri and Vernon (1964)

Figure 7. Generalized geology of the Middle Gulf area.

Figure 7. Generalized geology of the Middle Gulf area

may occur on the surface, underground, or in the atmosphere. Optimum development and management of the water resource depends to a large extent on an adequate understanding of these changes and the complex patterns of water circulation from ocean to atmosphere to land, and its return by various routes to the ocean or atmosphere. This complex water circulation system is known as "the hydrologic cycle".

The hydrologic system conveys all water from where it falls as rain either to the ocean or to the atmosphere. All streams, lakes, springs, sinks, and aquifers in the Middle Gulf area are part of a much larger complex hydrologic system. The amount of water in this system and the boundaries of the area contributing water to the system are constantly fluctuating in response to recharge and discharge.

Water moves from where it falls as rain, down-gradient through the various interconnected water-conveying components of the system. The principal conveying units may be streams in one area and aquifers — permeable rock units capable of storing and yielding usable quantities of water to wells or springs — in another area or a combination of both. The water may consecutively pass either from stream into aquifer, aquifer into stream, or may be evapotranspired to the atmosphere while enroute to the sea.

Lakes in one area may be directly connected to the aquifer and in another area only indirectly connected or they may be perched above the aquifer on an impermeable floor such that the lake is insulated from the effects of storage changes going on in the aquifer. For example, water may move from a lake by seepage through its bottom (direct) or water that is moving to the lake may be diverted through some upgradient connection (indirect) to the aquifer. Lakes may be drained by streams in one area and be landlocked in another. Generally, factors that affect water levels in one of the components of the system will affect water levels in another component to some degree; sometimes these effects are so small as not to be measureable. Pumpage from an aquifer may either directly or indirectly cause a decrease in a lake level or a decrease in the flow of a stream or where the lake is insulated from the aquifer it is not affected by aquifer responses at all. This appears to be the situation with some of the lakes in the heavily pumped areas of northwest Hillsborough County.

Water enters the Middle Gulf area as rainfall and ground-water inflow and is temporarily stored in streams, lakes or aquifers while enroute to points of discharge from the area. During periods of heavy rainfall, the rate of recharge to the area usually exceeds the rate of discharge; therefore storage increases and water levels rise accordingly.

The principal recharge to the aquifers occur during the summer months because precipitation during these months exceeds evapotranspiration.

When the discharge rate exceeds the recharge rate, the volume of water stored declines; this release of water stored at higher levels sustains movement down-gradient, and water levels fall accordingly.

Aquifers hold water in storage for longer periods than do lakes and streams, and in effect meter out water at more constant rates to the various points of discharge. Thus, discharge from the aquifers distributes the flow more evenly in time and maintains streamflow during dry periods. This is of great importance in the Middle Gulf area because about 80 percent of the runoff from the area is from ground-water storage. The percentage of runoff derived from ground water ranges from almost 100 percent in the northern part of the area to about 10 percent in the southern part. The runoff from the northern part is about five times greater than that from the southern part. The principal factors that determine the quantity of water stored in the aquifer are the volume of the aquifer, the percentage of drainable interconnected pore spaces in the aquifer and the elevation of the discharge outlet.

The estimated amount of recoverable water in the aquifer in the Middle Gulf based on an area of 1,700 square miles, an average of 1,000 feet of aquifer thickness, and a specific yield of 15 per cent, is 53 trillion gallons, or 160 million acre-ft. This volume in storage greatly exceeds some of the largest surface water reservoirs in the eastern United States. For a comparison, the storage capacity of some of the reservoirs are as follows (Thomas, 1956): Clark Hill, Savannah River, Georgia, 2.9 million acre-ft; Gunthersville, Tennessee River, Alabama, 1.0 million acre-ft; Wheeler, Tennessee River, Alabama, 1.1 million acre-ft; Kentucky Lake, Tennessee River, Kentucky, 6.0 million acre-ft; and Lake Martin, Tallapoosa River, Alabama, 1.6 million acre-ft.

The Middle Gulf area is underlain by a great and generally little appreciated natural reservoir of almost staggering proportions — almost 12 times the combined storage of all the above mentioned reservoirs. However to use this stored water effectively and protect it from waste, pollution and salt water encroachment, the aquifer must have careful management.

STREAMS

The general direction of flow of the few streams in the Middle Gulf area is southwestward or westward to the Gulf of Mexico. Streams in the northern part of the area generally originate as springs and

receive little direct runoff. Based on the short period of record (about 2 years) obtained during this study, it would appear that the flows of these spring-fed streams are among the largest in the state.

Streams in the southern part of the area receive substantial quantities of water from direct runoff. Generally the channels are poorly defined in the upper reaches but the channels in the lower reaches are better defined and are meandering.

The area contributing water to a stream is usually bordered by a topographic divide but because of the interconnection between ground and surface water in the Middle Gulf area, the ground-water divide may better define the area which contributes water to the stream than the topographic divide.

The principal streams draining the Middle Gulf area are Crystal, Homosassa, Chassahowitzka, Weekiwachee, Pithlachascotee and Anclote Rivers and Rocky, Sweetwater and Cypress creeks.

CRYSTAL RIVER

Crystal River heads at a group of springs in and around Kings Bay at Crystal River community, and flows about 7 miles to the Gulf of Mexico. Its channel, which ranges in depth from 2 to more than 20 feet, is relatively wide and in many places is weed-choked. The area contributing water to the river is estimated at 80 square miles. Little overland flow to the stream channel occurs and water gained is largely a ground-water increment.

The flow of the river is measured just above its confluence with Salt River and the average discharge to the gulf at this site during the study was about 930 cfs, or 600 mgd (average discharge for 24-hour period). The average range in stage at the measuring sites was about 1.5 feet. The stage is nearly identical to that of the Gulf of Mexico near Bayport, about 25 miles to the south.

The maximum flow carried by the channel during normal tidal cycles is about 4,000 cfs (2,600 mgd). During Hurricane Donna in September 1964 the maximum flow was estimated to be more than 10,000 cfs (6,500 mgd) — largely caused by wind tides — and stage exceeded 5 feet above msl. As a result of the high tides during the hurricane, as well as at several other occasions during the study, the net daily flow was negative, i.e., flow was inland.

Springs in Kings Bay, numerous springs east of the bay, seeps in the many canals excavated into the limestone bedrock, and springs in the tributaries contribute to the flow of Crystal River. The largest group of springs near the head of the river, locally known as Tarpon

Springs, appears to contribute much of the river's flow. A reconnaissance of tributaries below Salt River indicated no significant freshwater flow.

The fresh and salt water in the river appears to be well mixed and little, if any, stratification occurs. During tidal cycles, the change in direction of flow near the surface of the stream and near the bottom occur at about the same time.

The mineral content of the river water, which is due mostly to sodium chloride from sea water, is high near the mouth and decreases upstream as shown in figure 8. Near the head of the eastern-most tributaries, the water contains little or no salt (sodium chloride). The mineral content of water of the river at the gaging station just upstream from Salt River ranges from about 300 to 15,000 mg/l (milligrams per liter). By comparison, normal sea water contains about 20,000 mg/l chloride.

HOMOSASSA RIVER

Homosassa River and its spring complex lies about an equal distance (8 miles) from Crystal River on the north and Chassahowitzka River on the south. The river meanders through about 6 miles of swampy tropical lowlands to the Gulf of Mexico. Its average flow near the town of Homosassa, about halfway between the main springs and the Gulf, is about 390 cfs (252 mgd). Of this flow, springs in the headwaters contribute about 140 cfs (90 mgd); the Southeast Fork of Homosassa Springs about 80 cfs (52 mgd); and Halls River about 170 cfs (110 mgd).

The overland flow from the area surrounding Homosassa River is negligible. No stream channels have formed except for Hidden River, but numerous drainage canals and boat channels have been constructed in and near the town of Homosassa Springs.

Sea water migrates upstream during high tides as far as the main springs and the headwaters of Hall River. Springs in the headwaters of the Southeast Fork are relatively fresh, figure 9, whereas the main spring (Homosassa Springs) and small springs in the headwaters of Halls River, are salty (sodium chloride).

Hidden River, about 2 miles southeast of Homosassa, flows about 2 miles overland and disappears underground and apparently enters Homosassa River downstream from Homosassa. The average of five streamflow measurements of Hidden River during the study was about 30 cfs (19 mgd). The minimum stage of the river during this time was about 2 feet above msl. The flow of the river appears to be little affected by tides, although the mineral content of the water varies from about 400 to 3,400 mg/l as show in figure 10.

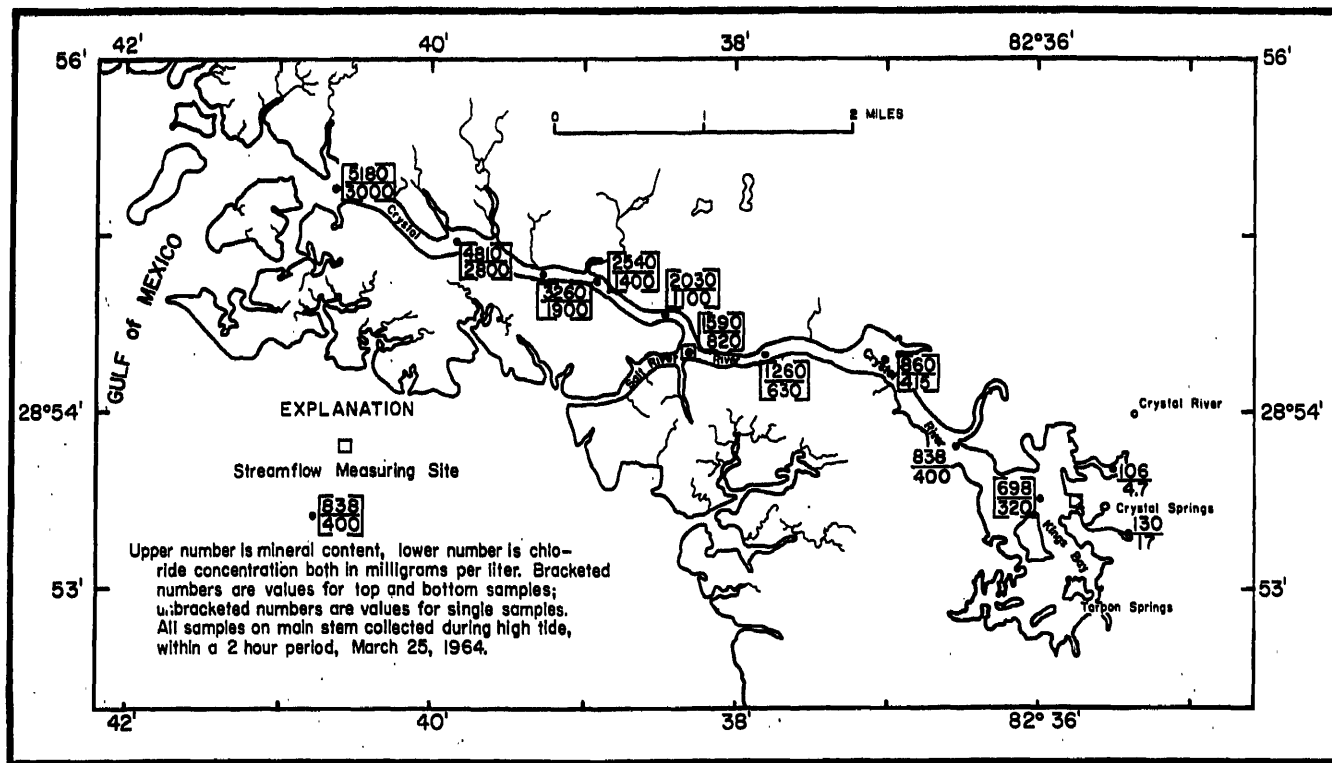


Figure 8. Map showing mineral content and chloride concentration of water at selected sites on Crystal River and adjacent areas, March 25, 1964

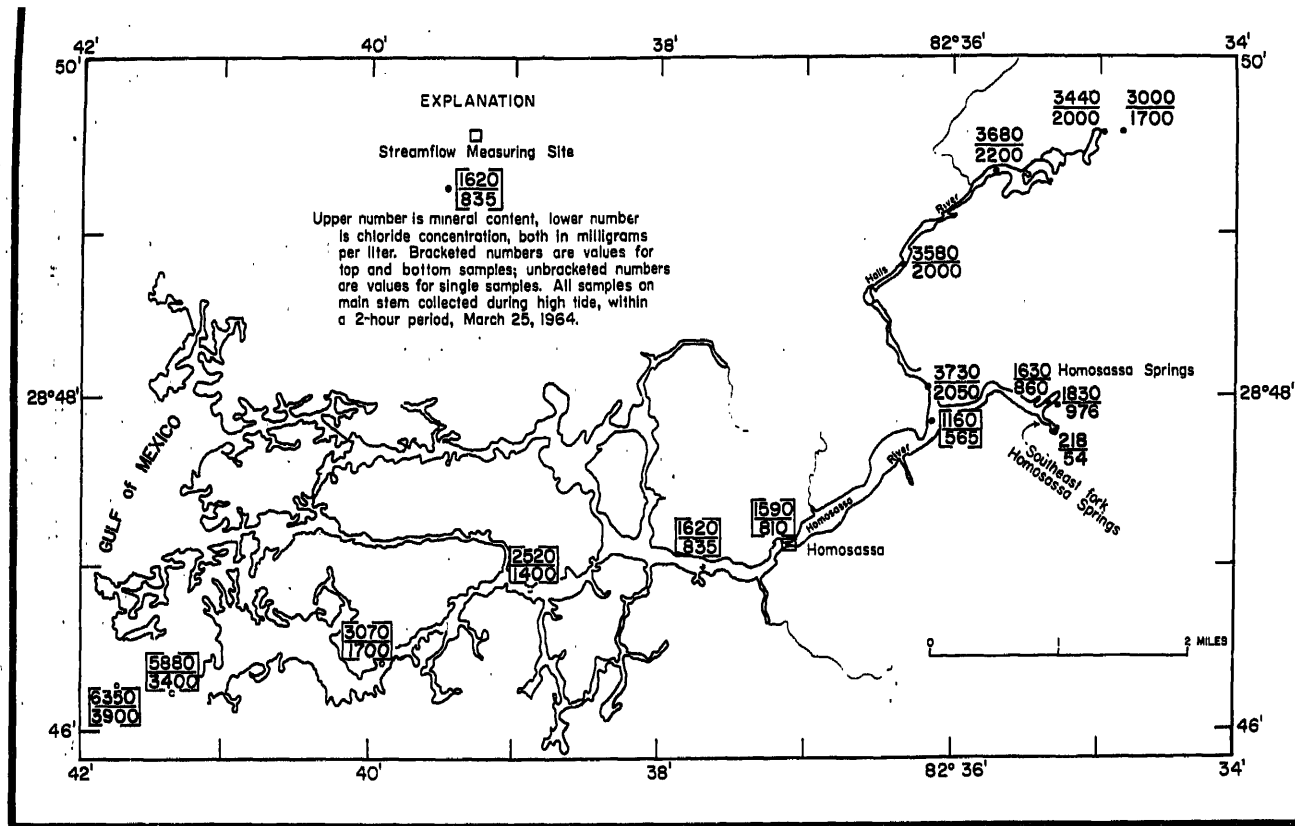


Figure 9. Map showing mineral content and chloride concentration of water at selected sites on Homosassa River and adjacent areas, March 26-27, 1964

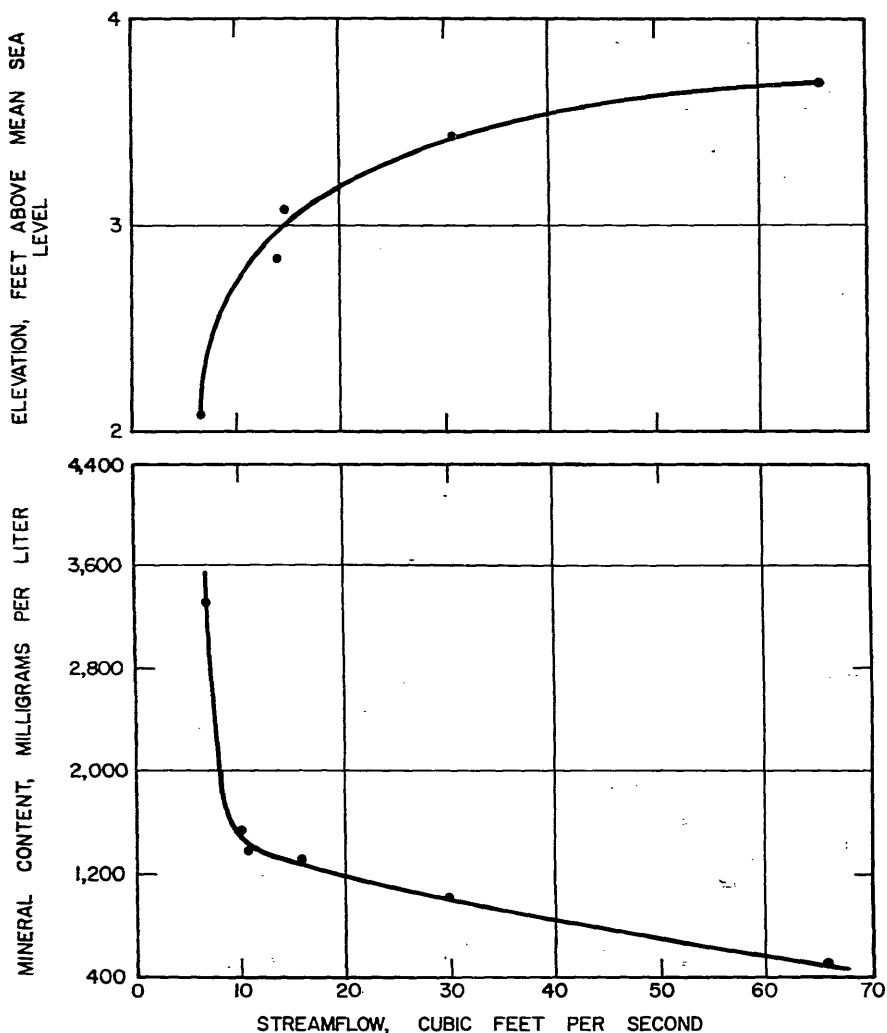


Figure 10. Graphs showing relation between stage and streamflow and mineral content and streamflow, Hidden River near Homosassa

CHASSAHOWITZKA RIVER

The Chassahowitzka River is a shallow stream that meanders through about 6 miles of tidal marshes and lowlands to the Gulf of Mexico. Its flow is derived chiefly from springs most of which are at the heads of tributaries in densely wooded areas that are practically inaccessible except by boat. Chassahowitzka and Crab Creek springs apparently contribute most of the flow (fig. 11). The average flow of Chassahowitzka River downstream from the springs at the gaging station below Crab Creek was about 140 cfs (90 mgd) for the period

January 1, 1964 — June 30, 1966. The average flow of the river, including all its tributaries, was estimated to be about 210 cfs (136 mgd) for the same period.

Springs just above the main boil of Chassahowitzka Springs are the freshest of any discharging to the river. Their mineral content when sampled was less than 300 mg/l, figure 11. In comparison, the mineral content of Chassahowitzka Springs ranged from about 300 to 2,100 mg/l. This wide range in mineral content is due in part to changes in salinity during tidal cycles. Because only daily samples were collected, the actual range of mineralization during tidal cycles has not been determined.

Crab Creek is about half a mile long, and enters the river from the north bank. Its average flow is about 50 cfs (32 mgd), derived from several boils at its head. The mineral content ranges from about 1,200 to 4,800 mg/l.

Lettuce Creek enters the river at the north bank about a quarter of a mile downstream from Crab Creek. The creek is about a quarter of a mile long and several small spring boils occur in the headwater area. Less than 5 cfs (3.2 mgd) issues from Lettuce Creek springs but the water is fresh (mineral content is less than 200 mg/l). The elevation of these springs is about 5 feet above msl — about the same elevation as the small springs upstream of the main spring boils of Chassahowitzka Springs (mineral content 300 mg/l).

Baird Creek enters the river about half a mile downstream from Lettuce Creek. Baird Creek appears to flow during all normal tides (the average of 5 streamflow measurements near low tide was about 30 cfs, 19 mgd) but may cease to flow during higher storm tides. The mineral content of the water at its mouth varied from 1,700 to about 6,000 mg/l.

Salt Creek enters the river about three-fourths mile downstream from Baird Creek. Salt Creek springs do not appear to flow during incoming or high tides. The mineral content of water at the head of Salt Creek was about 4,000 mg/l.

Potter Creek enters the river about half a mile downstream from Salt Creek. The flow of this stream averaged about 10 cfs, 6.4 mgd, (average of 5 discharge measurements near low tide). The springs at the head of the stream cease flowing during incoming or high tides. The mineral content of the water was about 1,000 mg/l.

Crawford Creek enters the river at the south bank about 2 miles downstream from Salt Creek. The flow from the creek averaged about 30 cfs (19 mgd), most of which appeared to come from a spring at the head of the creek. About a quarter of a mile downstream from the main

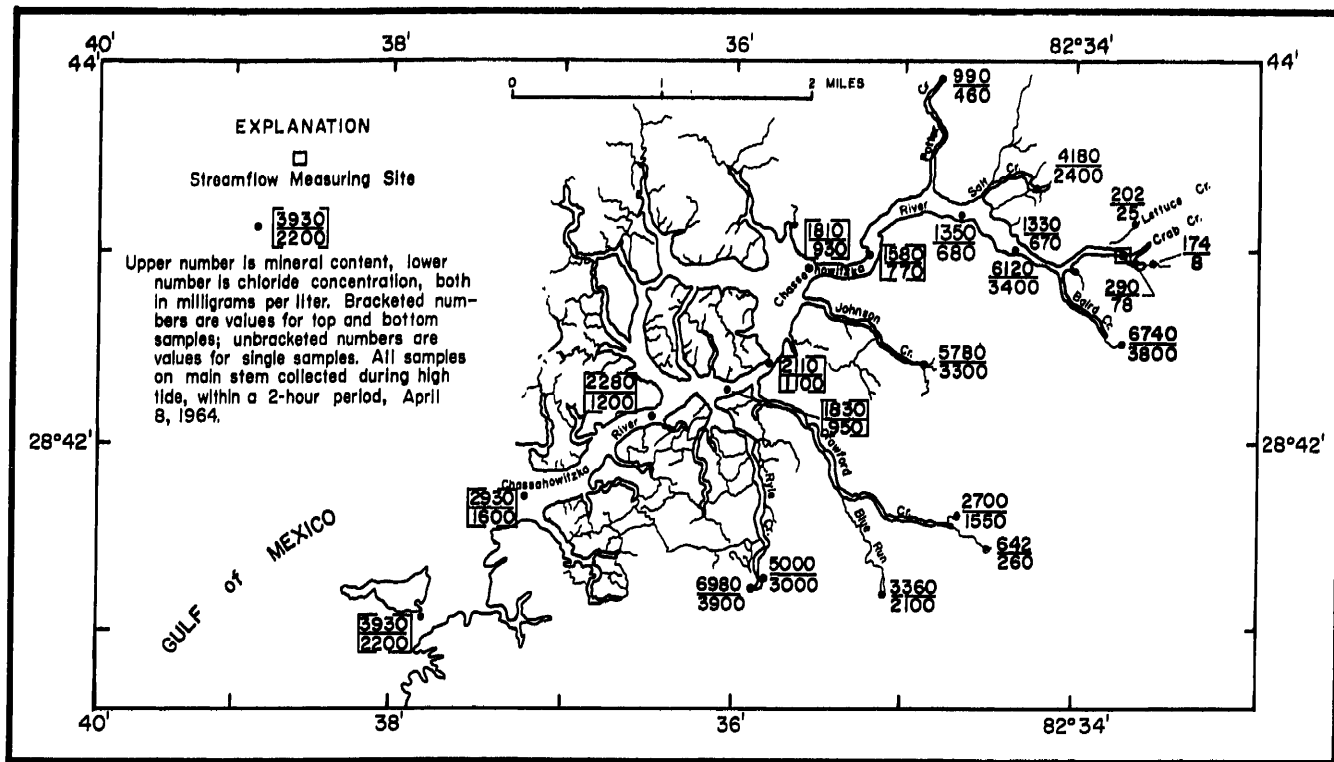


Figure 11. Map showing mineral content and chloride concentration of water at selected sites on Chasahowitzka River and adjacent areas, April 8-10, 1964

springs, several spring boils flow during low tides but not during incoming or high tides. The water issuing from these boils contains an iron bearing floc-like material, the exact nature of which has not been determined. The mineral content of water from the boils was about 2,700 mg/l.

The flow from Blue Run, a tributary of Crawford Creek, about a quarter of a mile downstream from the head springs, was small. The mineral content of its water was 3,400 mg/l in April 1964. However, a flow of 9.1 cfs (5.9 mgd) was measured on November 19, 1961 (Wetterhall, 1965).

Ryle Creek enters the Chassahowitzka River from the south bank about a quarter of a mile downstream from Crawford Creek. The flow appears to be negligible. However, some flow from small boils at the head of the creek was observed during low tides. Water from these boils contained a suspended red to yellowish-red, iron bearing floc-like material. This material is similar to that which comes from boils in Crawford and Baird creeks. The mineral content of the water from Ryle Creek boil was about 6,000 mg/l.

Blind Creek (not shown on map) enters Chassahowitzka Bay about 3½ miles downstream from Ryle Creek. The source of the creek's water is from several boils in the headwater area. The mineral content of the water from these boils ranged from about 5,000 to 14,000 mg/l.

WEEKIWACHEE RIVER

Weekiwachee River heads at Weekiwachee Springs, about 5 miles southeast of Bayport. The river meanders through about 7 miles of swampy lowlands to the Gulf at Bayport. Its channel is well-defined and is cut into the underlying bedrock. Many springs flow into the stream through openings in the streambed.

The flow of the river is derived chiefly from Weekiwachee Springs. During January 1964 to June 1966, these springs had an average flow of about 220 cfs (142 mgd). In this same period, the average flow of the river at a gaging site about 5 miles downstream from the springs was about 260 cfs (168 mgd). The large quantities of water flowing in these streams can be judged by comparison with the water currently (1966) supplied by the Eldridge-Wilde, Cosme, and Section 21 well fields, 45 mgd, or 70 cfs.

The water of Weekiwachee River is low in mineral content from the headwater (at Weekiwachee Springs) to near its mouth, figure 12. The mineral content of Weekiwachee Springs is nearly constant at 145 mg/l.

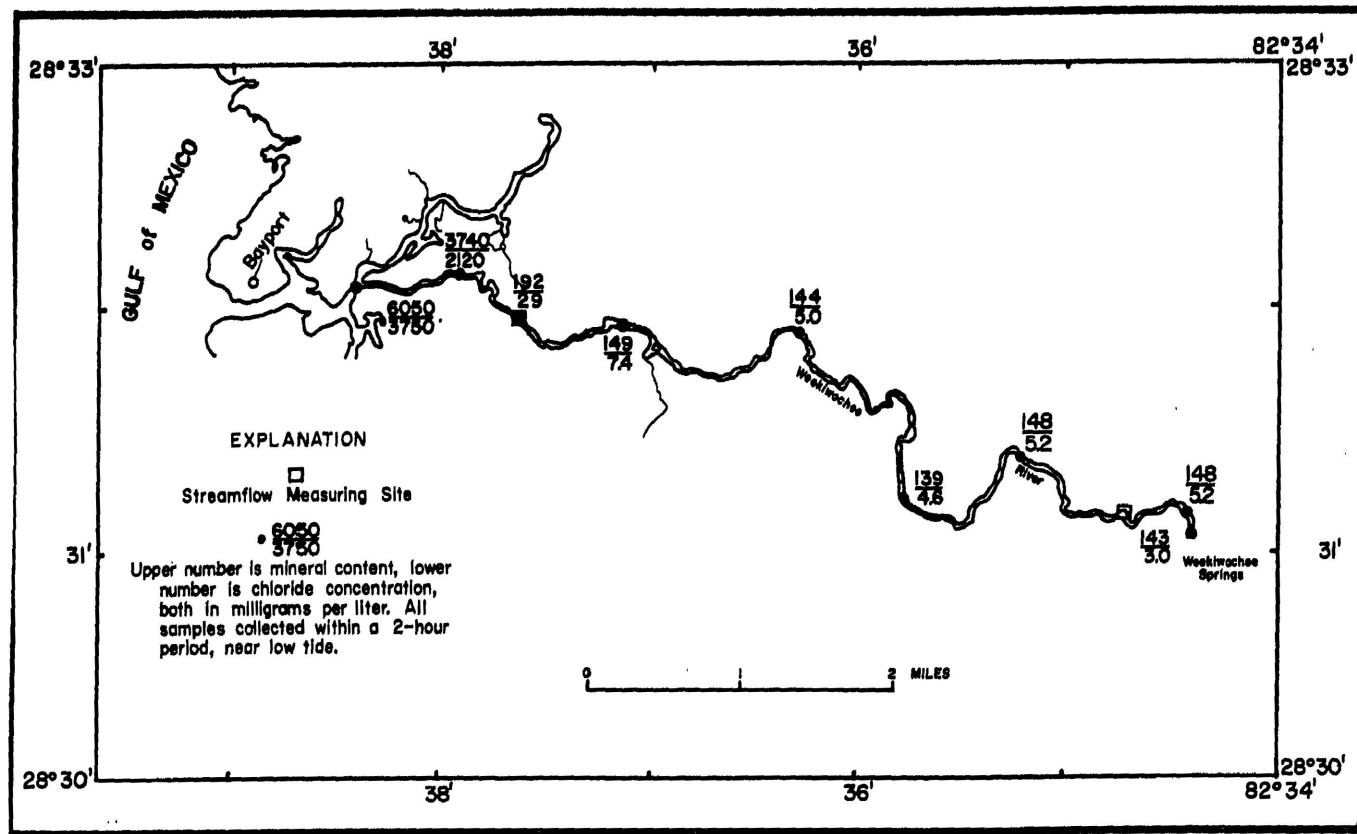


Figure 12. Map showing mineral content and chloride concentration of water at selected sites on Weekiwachee River, April 29, 1964

PITHLACHASCOTEE RIVER

The Pithlachascotee River rises in south-central Hernando County and flows southwestward through Pasco County to enter the Gulf of Mexico at New Port Richey. The major tributaries are Jumping Gully and Five Mile Creek. The upper reaches contains many lakes, sinks, and depressions. The middle and lower reaches are swampy, and ill-defined flow is affected by tide near the mouth. The estimated average flow at the mouth was 55 cfs (36 mgd). Jumping Gully contributes about 25 cfs (16 mgd) to this flow and Five Mile Creek less than 5 cfs, or 3.2 mgd, (estimated). The remainder, 25 cfs (16 mgd) is ground-water seepage through the channel bottom downstream from these tributaries.

Land elevations range from 150 feet above msl in the headwaters to mean sea level at the mouth. The slope of the river channel is about 9 feet per mile in its upper reaches, about 1.5 feet per mile in the middle reaches, and about 5 feet per mile in the lower reaches.

In the headwater area, small channels connect lakes such as Hancock, Moody, Middle, and Iola. These lakes have no visible outflow channel to the Pithlachascotee River. Neff and Mountain lakes are interconnected with a surface channel and likewise have no visible outflow channel. Lakes Hancock and Neff, the down-gradient lakes in each of the chains, have sinkholes open to the Floridan aquifer through which drainage occurs and both lakes, in the past few years, have been greatly reduced in size and depth. Neff Lake has become essentially a wet prairie.

Crews Lake is divided north and south by an earthen dike that contains a culvert connecting the two parts. Most of the inflow is from Jumping Gully which flows into the southern part and then through a culvert in the dike to the northern part. The northern part contains a sinkhole through which lake water can freely drain to underlying aquifers. This sequence is indicated by the following factors: (1) when lake stages decline below the culvert, lake levels in the northern part decline at a faster rate; (2) lake levels have declined sufficiently to permit observation of inflow to the sinkhole; and (3) local reports indicate that the lake has completely drained through the sinkhole during exceptionally dry years. The peak inflow to Crews Lake from Jumping Gully was about 920 cfs (595 mgd) on September 18, 1964. At the outlet, the peak flow was about 270 cfs or 175 mgd (as determined from a rating curve extended above 222 cfs, or 143 mgd).

The peak flow of the Pithlachascotee River at New Port Richey, 1,410 cfs (911 mgd) on September 11, 1964, preceded the peak flow at Jumping Gully by 7 days. No secondary peak was observed at New Port

Richey. The rain that caused this peak occurred September 10 – 13. Because the peak occurred downstream prior to the peak upstream and because of the presence of many sinkholes in upgradient areas, much of the flow at New Port Richey was derived from the underground reservoir.

Water in the upper reaches of the river is low in mineral content (generally less than 100 mg/1). The mineralization increases downstream and is highest in the lower reaches owing to tidal mixing with sea water. Springs near the coast are generally high in mineral content (14,000 mg/1) of which about 8,000 mg/1 is chloride.

The mineral content of the water of the river varies seasonally at the measuring site above the tidal influence. The highest concentrations occur in late May or early June and the lowest generally in August or September. The variation in mineral content is related to the source of the river's flow. During low-flow periods most of the water is seepage from the Floridan aquifer, and the mineral content is relatively high, chiefly calcium bicarbonate. During high flow periods most of the water is overland flow and the mineral content of the water is relatively low.

The following relations were used to estimate a separation of the hydrograph for the Pithlachascotee River into components of water from the Floridan aquifer and water from overland flow and the shallow aquifer, figure 13. The equation used to determine this separation is given below:

$$Q_1 + Q_2 = Q_3$$

$$C_1 Q_1 + C_2 Q_2 = C_3 Q_3$$

where Q_1 is the component of seepage in cfs, from the shallow aquifer and from overland flow;

Q_2 is the component of seepage in cfs, from the Floridan aquifer;

Q_3 is the streamflow in cfs, of Pithlachascotee River near New Port Richey;

C_1 is 30, the average mineral content in mg/1 of typical water from overland flow and the shallow aquifer;

C_2 is 275, the average mineral content in mg/1 of typical water from the Floridan aquifer in the Pithlachascotee River area;

C_3 is the daily mineral content in mg/1 of water from Pithlachacotee River near New Port Richey.

Computations using this equation indicate that water contributed

by the Floridan aquifer to the stream averaged about 8 cfs (5.2 mgd) for the 2.5 years of study. Therefore, during this period the aquifer contributed about 15 percent of the average flow of the river. The computations show that at high streamflow the contribution from the Floridan aquifer to the river is greatest although this contribution is only a small percentage of total high streamflow. Conversely, during periods of low streamflow, the contribution from the Floridan aquifer to the river is lowest but comprises a large percentage of total low flow; the remainder is derived mostly from the shallow aquifer.

ANCLOTE RIVER

The Anclote River rises in south-central Pasco County and flows westward to the Gulf of Mexico. The area adjacent to the river is sparsely populated, and the major land uses are tree farming, cattle ranching and citrus farming. Land surface elevations is 80 feet above msl in the headwaters. The slope of the river ranges from about 2 feet per mile in the reach of channel near Elfers to 5 feet per mile in the headwaters. The average flow of the river near Elfers for the period of study was 95 cfs (61 mgd).

The mineral content of the river is greater near the Gulf (about 22,000 mg/l) than upstream (about 220 mg/l). Above the reach of the river affected by tidal inflow, the mineral content at low flow is due chiefly to calcium bicarbonate. The surficial deposits underlying the Anclote River consists mostly of sand and clay which are essentially insoluble in water. Therefore, the calcium bicarbonate in the river water is due principally to seepage from the Floridan aquifer.

Flow relations and chemical quality of water of the Anclote River and aquifers were used again to estimate the contribution of the Floridan aquifer to the stream and to separate the streamflow hydrograph of the river into components of water from the Floridan aquifer and water from overland flow and the shallow aquifer, figure 14. Computations indicate that seepage from the Floridan aquifer averaged about 10 cfs (6.4 mgd) for the period of study. Therefore, during this period the aquifer contributed about 10 percent of the average flow of the river.

BROOKER CREEK

Brooker Creek rises in northwestern Hillsborough County near Keystone Lake and flows generally westward through swampy areas, in places with no defined channel, to Lake Tarpon in northeastern Pinellas County. Land-surface elevation ranges from about sea level at Lake Tarpon to 60 feet above msl in the headwaters. The slope of the

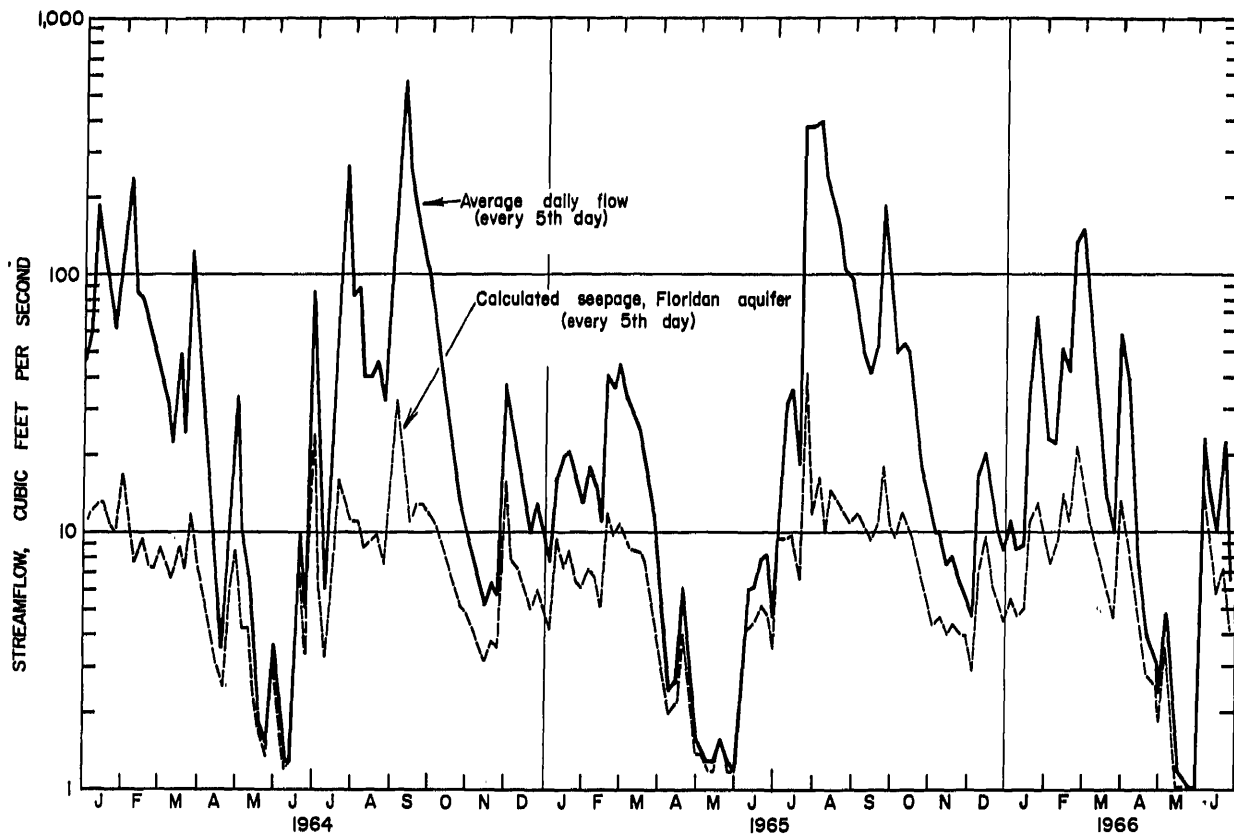


Figure 13. Graph showing comparison of the average daily flow of the Pithlachascotee River near New Port Richey and Floridan aquifer seepage (calculated) to the river

river varies from about 5 feet per mile in the headwaters to about 2.5 feet per mile near Lake Tarpon. For the period of study its average flow near Lake Tarpon was 25 cfs (16 mgd).

A canal recently (1968) constructed by the Southwest Florida Water Management District connecting Lake Tarpon with Old Tampa Bay carries the runoff from the Brooker Creek area into the bay.

CURLEW CREEK

Curlew Creek, a small stream north of Dunedin, drains west into the Gulf of Mexico. The channel slope ranges from about 60 feet per mile for a short distance in the headwaters to 5 feet per mile near the mouth. The creek heads in the hilly area northwest of Safety Harbor. The average flow at the mouth of the creek was estimated to be about 20 cfs (13 mgd) during the period of study.

STEVENSON CREEK

Stevenson Creek heads in the hilly area near the central part of Pinellas County and drains northwestward to the Gulf of Mexico. The lower reach of the creek is tidal. The average flow at its mouth was estimated to be 20 cfs (13 mgd) during the period of study.

McKAY CREEK

McKay Creek in the southwestern part of Pinellas County, rises in the hilly area south of Clearwater and flows to the Gulf of Mexico. The flow at the mouth of the creek was estimated to be 5 cfs (3.2 mgd) during the period of study.

SEMINOLE LAKE OUTLET

Seminole Lake lies south of Clearwater. This lake was created in 1950 by damming the upper reach of Long Bayou, a salt-water inlet. The freshening of Seminole Lake is discussed in this report in the section entitled "Lakes". The average flow at the lake outlet was 13 cfs (8.4 mgd) during the period of study.

ALLEN CREEK

Allen Creek is northeast of St. Petersburg and flows eastward to Old Tampa Bay. Its flow was measured in 1948 - 50 but was not measured during this study. However, by correlating the 1948 - 50 flows with those of other streams in the area during the same period, the flow at the mouth during this study period was estimated to be 15 cfs (9.7 mgd).

ALLIGATOR CREEK

Alligator Lake is near the town of Safety Harbor and was formed by damming off a salt-water inlet. Alligator Creek flows into Alligator

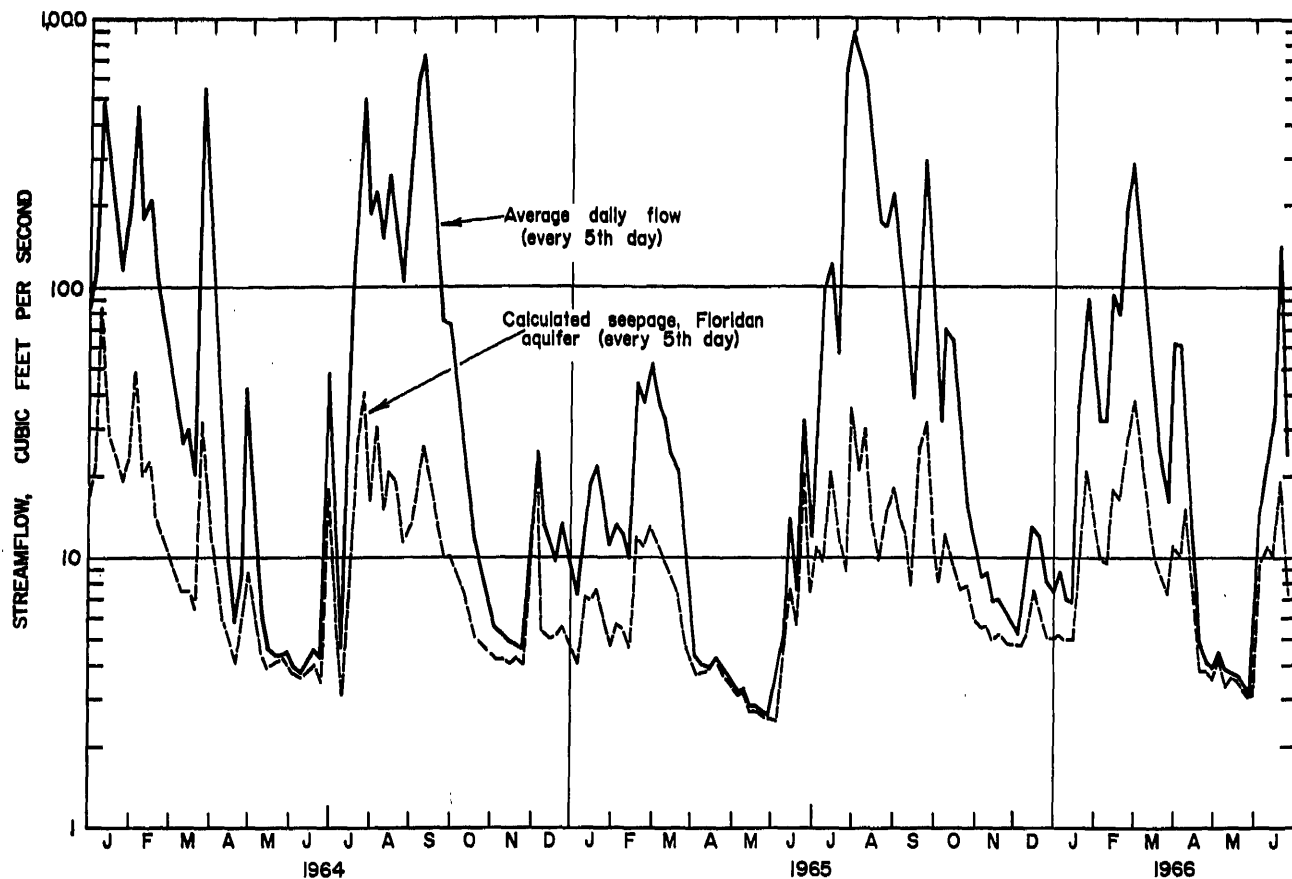


Figure 14. Graph showing comparison of average daily flow of the Anclote River near Elfers and Floridan aquifer seepage (calculated) to the river

Lake and drains the hilly area west of Safety Harbor. The average flow of Alligator Creek for the period of study was 8 cfs (5.2 mgd).

ROCKY CREEK

Rocky Creek rises in north-central Hillsborough County and flows southward to upper Old Tampa Bay.

It drains about 35 square miles and the average flow at the gaging station near the mouth for the period of study was 40 cfs, or nearly 26 mgd. The Rocky Creek drainage area is sparsely populated except near lakes in the upper reaches and near upper Old Tampa Bay in the lower reaches. Some of the lakes in the upper reaches are Hobbs, Cooper, Thomas, Starvation, and Round, the levels of some of which have been lowered by pumpage from the underlying Floridan aquifer. Tributaries of Rocky Creek drain the land surface that includes Cosme and Section 21 well fields.

A flood relief channel in the lower reaches, constructed in 1966 as part of the Upper Tampa Bay watershed project of the U. S. Soil Conservation Service, carries flood flow southwest into upper Old Tampa Bay.

The mineral content ranges from about 35 to 60 mg/l in the middle and upper reaches of the creek. The lower reach is tidal and contains concentrations of chloride approaching those of sea water.

SWEETWATER CREEK

Sweetwater Creek rises in western Hillsborough County and flows southward into upper Old Tampa Bay. Its channel slopes about 10 feet per mile in the middle reaches and about 1 foot per mile in the lower reaches. The drainage area is more than 50 feet above msl in the headwaters. In the headwaters, the land surface is poorly drained and is occupied by many relatively shallow large lakes such as Magdalene, Bay, Ellen, Carroll, and White Trout, all of which are interconnected by canals and culverts. The upper reach of the stream also contains many small lakes, ponds, and sinks along the eastern topographic divide which is adjacent to the sinkhole complex known as Blue Sink. During periods of extremely high water, such as occurred during the floods of 1960, some of the drainage from nearby lakes flows into Blue Sink.

During the period of study the average flow at the mouth was an estimated 25 cfs, or more than 16 mgd. The flow of this stream is regulated and in periods of high water, Sweetwater Creek receives some overflow from Cypress Creek through a low, swampy area separating the two streams.

The water of Sweetwater creek is a calcium bicarbonate type in the headwaters and sodium chloride at the mouth. The mineral content

ranges from about 50 mg/l in the headwaters to about sea-water concentration at the mouth.

CYPRESS CREEK

Cypress Creek rises in northern Pasco County and flows southward to the Hillsborough River. The channel is not well-defined except in the middle reaches near Worthington Gardens, where the banks are relatively steep. In the upper reaches the creek emerges from low sand hills and sinkholes and in the lower reaches south of Worthington Gardens it flows through swampy lowlands to the Hillsborough River.

Streamflow was measured periodically at several sites and continuously near San Antonio during the study period. Near San Antonio in the upper reaches, the average flow was 41 cfs (26 mgd), and near the mouth of the river the estimated flow was 190 cfs (122 mgd).

The water of Cypress Creek is a calcium bicarbonate type and its mineral content ranges from about 25 to 150 mg/l. The mineralization is lowest during periods of high flow and highest during periods of low flow. The calcium bicarbonate water represents seepage from the Floridan aquifer.

The following relations were used to estimate the contribution of the Floridan aquifer to the stream and to separate the streamflow hydrograph of the creek into components of water from the Floridan aquifer and from overland flow and the shallow aquifer, figure 15. The equation is the same as that used in the discussion of the Pithlachascotee River except that C_1 is 28 and C_2 is 165. Computations show that seepage from the Floridan aquifer averaged about 7 cfs for the 2.5-year study. Therefore, during this period the aquifer contributed about 20 percent of the average flow of the creek (near San Antonio). Computations also show that at high streamflows discharge from the Floridan aquifer is a negligible part of the total streamflow but at low flow the creek consists chiefly of water derived from the Floridan aquifer.

TROUT CREEK

Trout Creek heads just east of U.S. Highway I-75 and south of State Highway 52 and flows southward to the Hillsborough River. The area is sparsely populated, low and swampy, and is used mostly for cattle ranching. The channel slope ranges from about 10 feet per mile in the headwaters to less than 5 feet per mile at the mouth. The streamflow averaged about 70 cfs (45 mgd) for the period of study as determined by correlating the streamflow of Trout Creek with that of Cypress Creek and New River.

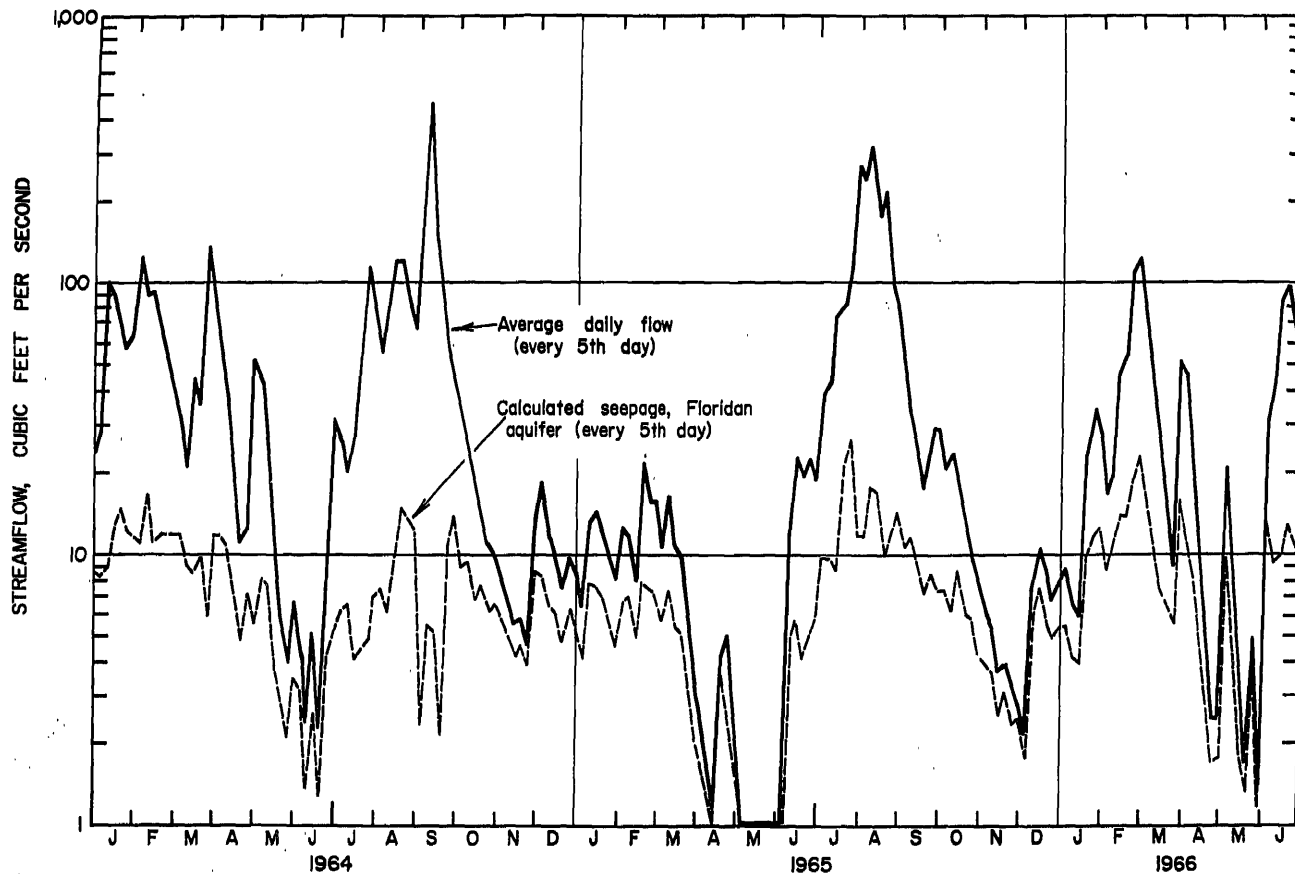


Figure 15. Graph showing comparison of average daily flow of Cypress Creek near San Antonio and Floridan aquifer seepage (calculated) to the creek

BUSY BRANCH

Busy Branch, east of Trout Creek and south of State Highway 52, flows generally southward to the Hillsborough River. The area adjacent to this stream is sparsely populated, and is flat and swampy and is dotted with small lakes and ponds. The channel slope is about 10 feet per mile for its entire length. Periodic streamflow measurements were made at a site near the mouth, and an average streamflow of about 5 cfs (3.2 mgd) for the period of study was determined by correlation with New River.

NEW RIVER

New River begins south of San Antonio and flows southward into the Hillsborough River. The flow of the river averaged about 15 cfs (9.7 mgd) for the period of study.

LONG-TERM TRENDS IN STREAMFLOW

Long-term hydrographs for three streams are shown in figure 16. The Hillsborough River near Zephyrhills is near the southeastern boundary of the Middle Gulf area; the Anclote River near Elfers is in the western part; and the Withlacoochee River near Holder is near the northeastern boundary of the area. These hydrographs show that stream-flow during the study period approximated the average for the long-term period.

The flow of Weekiwachee Springs west of Brooksville has been measured periodically since 1917. From 1917 through 1966, 300 flow measurements were made, and the average of these measurements was 174 cfs (112 mgd). The maximum and minimum flows measured during this period were 275 (178 mgd) and 101 cfs (65 mgd), respectively. For the study period, the average of 18 flow measurements was 223 cfs (144 mgd). The maximum and minimum measured flow during the study period was 275 cfs (178 mgd) and 170 cfs (110 mgd), respectively.

The flow of Homosassa Springs at Homosassa Springs has been measured periodically since 1932. From 1932 through 1966, 25 flow measurements were made. The average of these measurements was 199 cfs (129 mgd), and the maximum and minimum flows measured were 257 cfs (166 mgd) and 125 cfs (81 mgd), respectively. The average of 12 measurements of the flow made during the study period was 224 cfs

(145 mgd). The maximum and minimum measured flow during the study period was 257 cfs (166 mgd) and 170 cfs (110 mgd), respectively.

LAKES

GENERAL CHARACTERISTICS

Lakes occur in most of the Middle Gulf area but are more numerous in the eastern and southern part. The origin of Florida lakes has been discussed by White (1958) and by Matson and Sanford (1913).

Matson and Sanford (1913, p. 25) state that "In the central part of the peninsula are lakes and swamps which appear to be the result either of unequal depression of the surface sands or of solution of the subjacent limestone and consequent lowering of the surface. ***Some of the lakes are shallow and resemble those of the coastal belt, but others are deep basins partly or wholly enclosed by a rim of rock. Many of the smaller swamps contain peat or muck, but few of the deposits attain any great thickness and many of them form only a thin coating of partly decomposed vegetable matter mingled with more or less sand."

Figure 17 shows areas of comparable range of stage fluctuations of selected lakes within the area during the period of study. The fluctuations show a range of less than two feet to more than four feet. Lakes in the east-central and southern parts of the area have the greatest range in fluctuation. Many of these lakes are hydraulically connected to the Floridan aquifer through sinkholes.

Stage fluctuations of a lake in an upgradient area, stage fluctuations of a lake in a downgradient area; stage fluctuations of a lake affected by ground-water withdrawals, and stage fluctuations of lakes formed by damming tidal inlets are compared on figure 18. Lake stages tend to be highest in the summer or early fall during the rainy season and lowest in late spring during the dry season. Lake levels in the upgradient areas of the Middle Gulf tend to fluctuate through a greater range than in lakes in downgradient areas. Where lakes are affected by ground-water withdrawals, levels tend to decline at greater rates than in lakes not so affected.

The range of fluctuations is minimal in controlled lakes, such as Alligator and Seminole lakes, which were formed by damming tidal

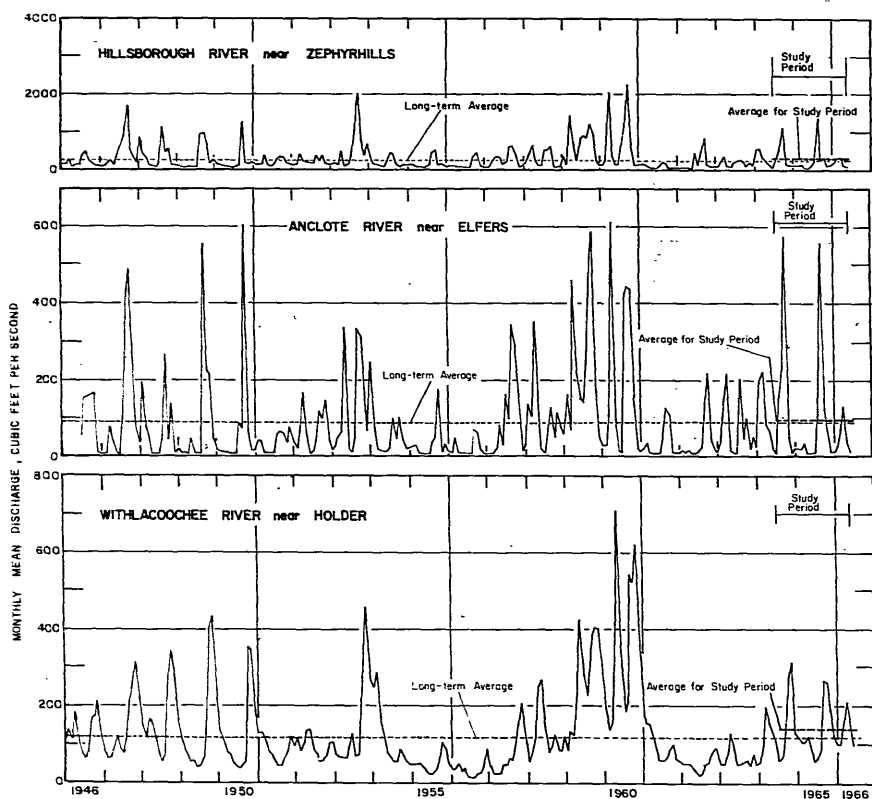


Figure 16. Hydrographs of long-term streamflow for selected streams in the Middle Gulf area

inlets. Continuous gaging station records on these lakes show no evidence of tidal fluctuation, and seasonal fluctuations are minimal.

Water from lakes in the northern and eastern parts of the area contain a lower mineral content than water from lakes in the western part of the area, figure 19. Waters of some lakes near the coast that contain high mineral content have sodium chloride as the principal constituent. In other coastal lakes and lakes in the southwestern part of the area, calcium bicarbonate is the principal constituent.

The chloride concentration of Seminole Lake decreased from about 2,300 mg/l in May 1950, when the dam was completed, to 25 mg/l in November 1957, figure 20. The water in this lake has contained less than 250 mg/l chloride since October 1951, about 2 years after completion of the dam. The chloride concentration has ranged from

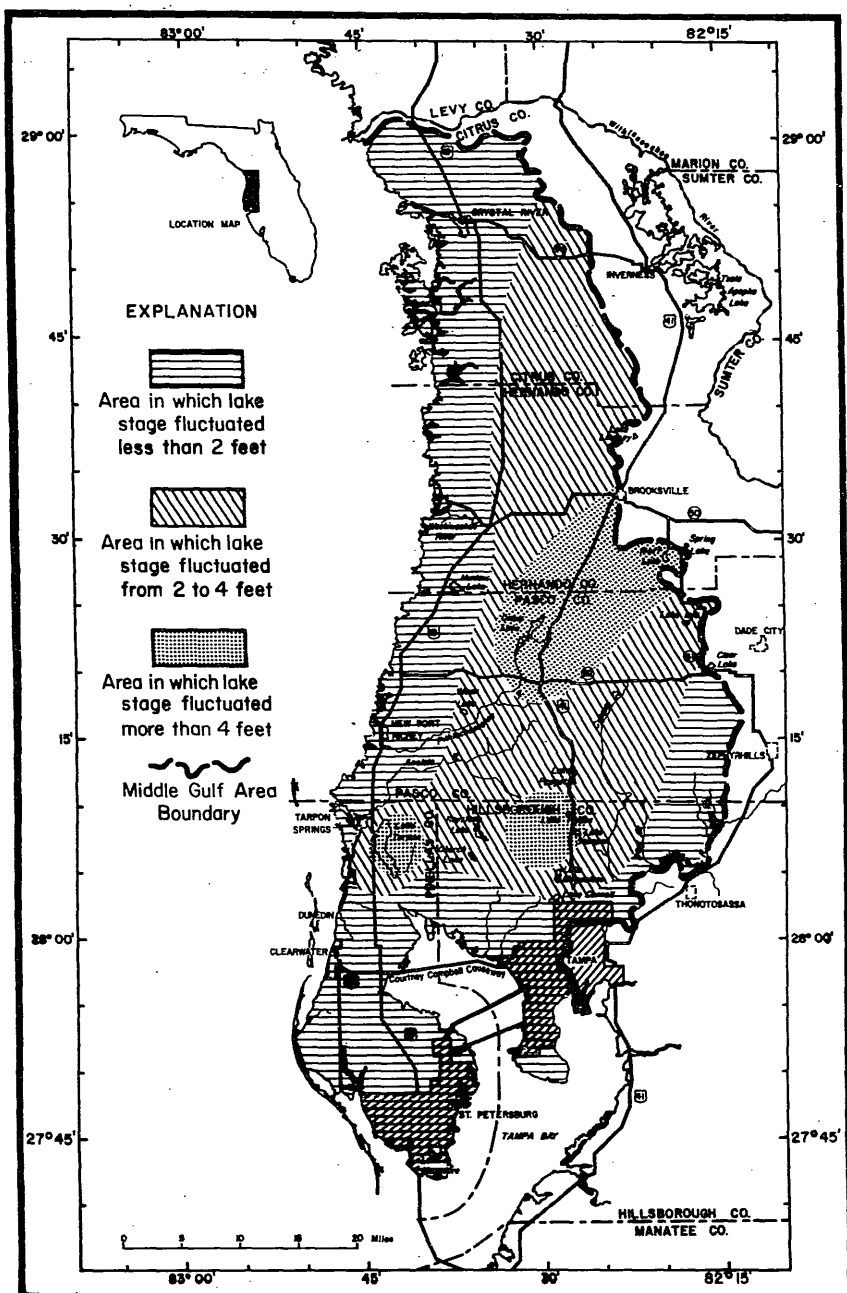


Figure 17. Map showing ranges of fluctuation of selected lakes in Middle Gulf area during the study period

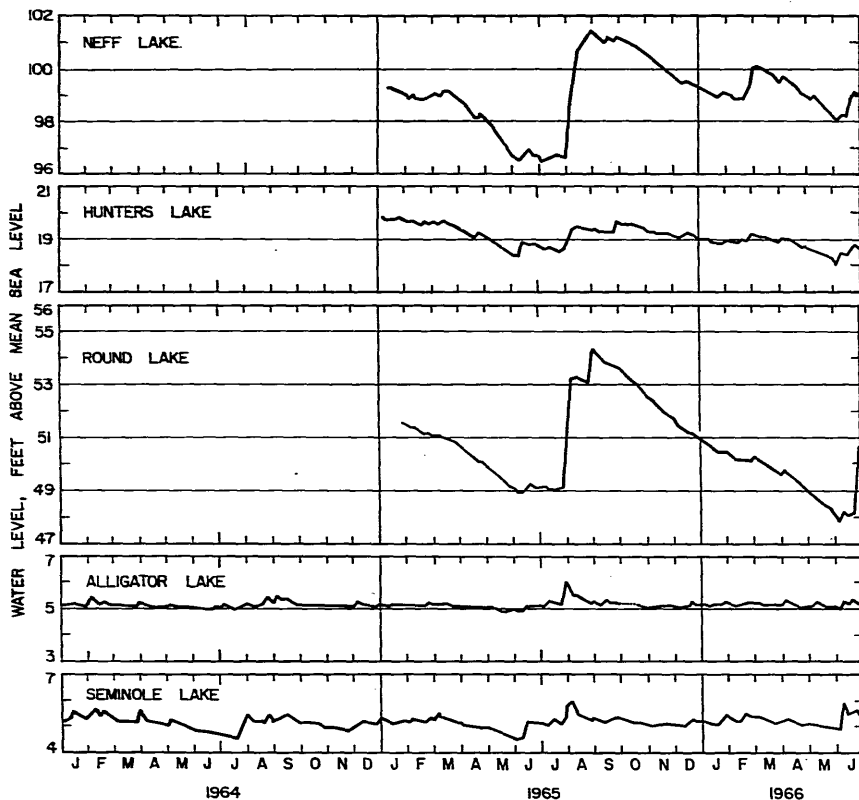


Figure 18. Hydrographs showing comparison of stage fluctuations of Neff Lake (in upgradient area), Hunters Lake (in down-gradient area), Round Lake (affected by ground-water withdrawals), and Alligator and Seminole Lakes (stage controlled)

about 30 to 180 mg/l since 1957. The average outflow from the lake during the study period was about 10 cfs (6.4 mgd).

The evaporation from lakes in central Florida appears to be about equal to the average annual rainfall (Pride 1965). The mineral content of most of the lakes is relatively low and periodic sampling of several lakes indicated little seasonal variation. The low mineral content is controlled not only by rainfall and evaporation but by constant movement of ground water through the lakes. Some of the lakes that have a relatively high concentration of calcium bicarbonate may receive water by upward leakage from the Floridan aquifer.

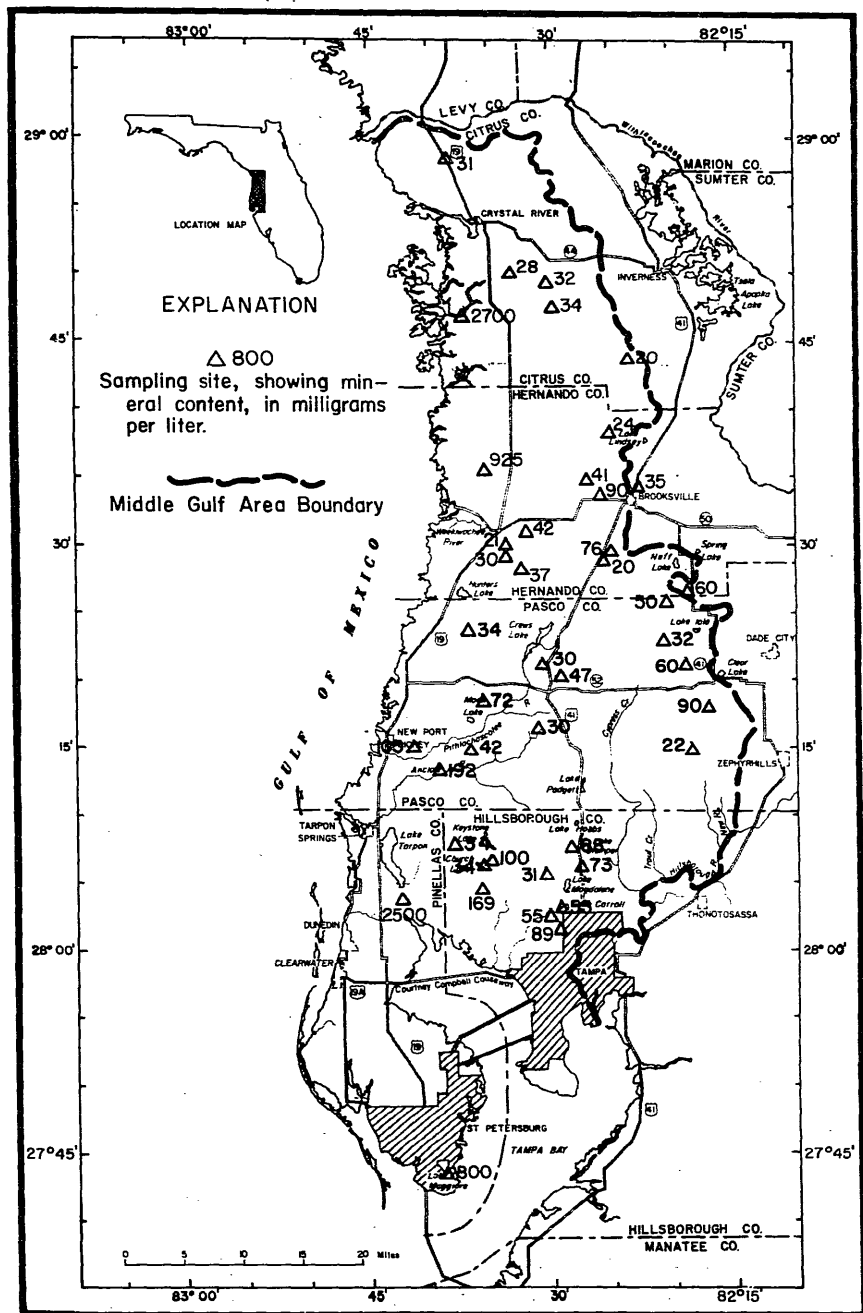


Figure 19. Map showing mineral content of water in selected lakes in and near the Middle Gulf area, May 1965.

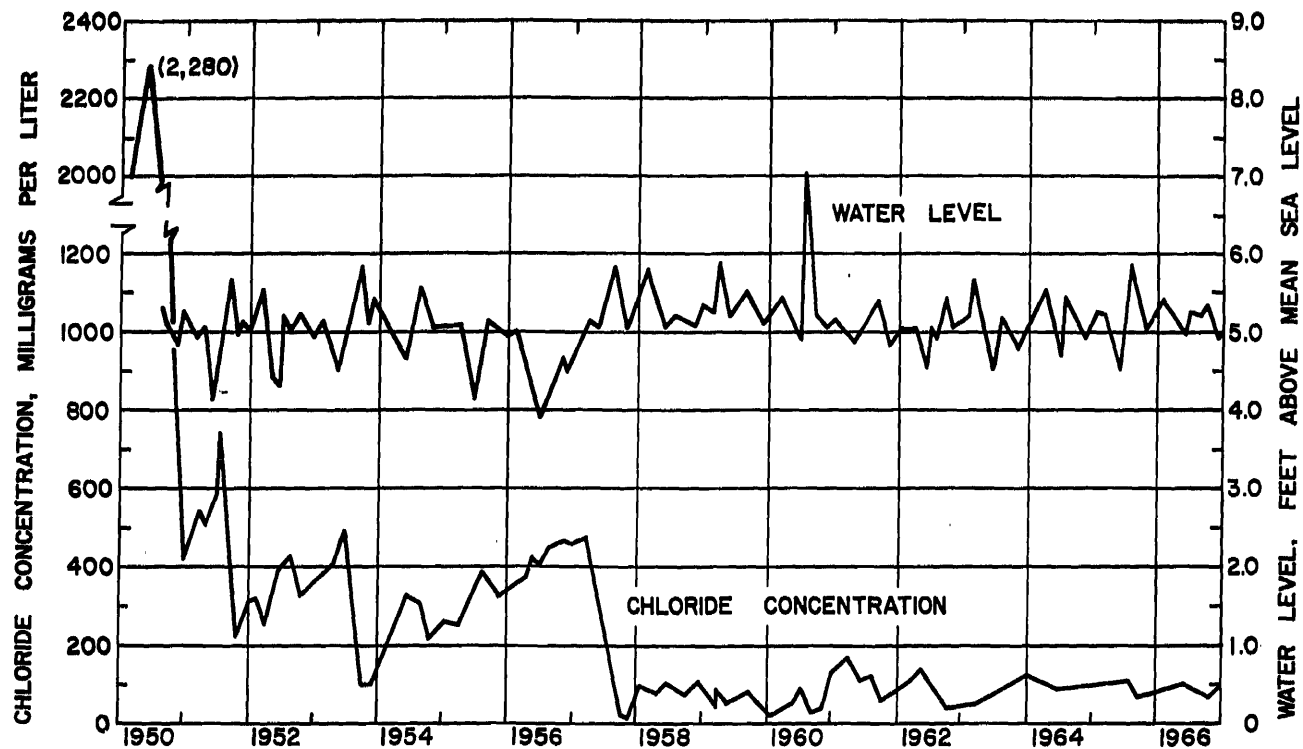


Figure 20. Graph showing changes in chloride concentrations and water levels of Seminole Lake, 1950-1966

LAKE TARPON

Lake Tarpon and its underground connection with Spring Bayou has been studied in considerable detail by Taylor (1953) and Heath (1954). Wetterhall (1965) made additional measurements of salinity in the sink area. No extensive study of the lake was conducted as a part of this investigation, although continuous stage was recorded for Lake Tarpon and Spring Bayou and daily water samples were collected at Lake Tarpon.

Figure 21 shows the water levels in Lake Tarpon and Spring Bayou, and the mineral content of water in Lake Tarpon during the period of study. The changes in mineral content are due mostly to changes in salinity, and appears to be lowest during the early fall months at the end of the rainy season and highest during the early summer months, the dry season. During this study the lowest mineral content, 630 mg/l, was observed in late September 1964. This low occurred about 10 days after the lake stage reached the highest level for the study period. From this low, the mineral content increased to its highest value (3,600 mg/l) in late July 1965. During this period of higher mineral content, the lake stage varied from about 1 to 3 feet and generally was about 2 feet above msl. A sharp decrease in mineral content occurred immediately following the high concentration recorded in late July. At the same time, lake stage showed a sharp rise, followed 10 days later by a decline. Thus, the most significant decreases in mineral content occurred following periods of highest lake stages. The sharp decrease in mineral content in the period July – August 1965 is due to displacement of salty water in Lake Tarpon by fresh water inflow from Brooker Creek and rainfall. Dilution of the mid-July 1965 Lake Tarpon water by fresh-water inflow could not account for the sharp decrease in mineral content coincident with a decrease in stage. The stage decrease was caused by drainage of the lake through the sinkhole which resulted by early September in low stages in the lake and low mineral content of water at the sampling site.

A comparison of the water stages in Spring Bayou with the water stages of Lake Tarpon shows that water stages of Lake Tarpon are generally higher than those in Spring Bayou. Discharge from the lake through Spring Bayou occurred when the lake stages were above the high-tide stage in Spring Bayou. However, the same head difference between Lake Tarpon and Spring Bayou does not always cause flow through the underground channel. Therefore, discharge from the lake is probably due to a combination of head difference and the salinity

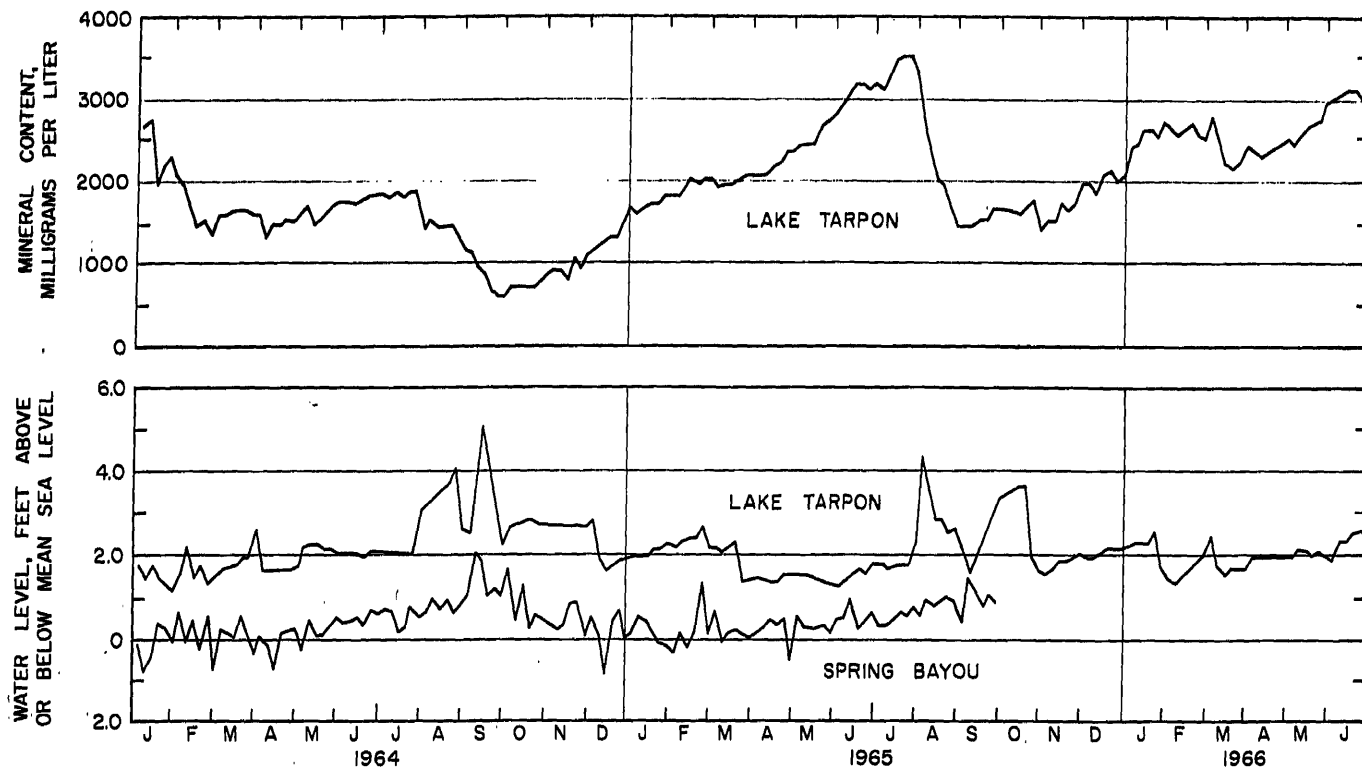


Figure 21. Water levels in Lake Tarpon and Spring Bayou and the mineral content of water in Lake Tarpon during the period of study.

conditions in the underground channel connecting Lake Tarpon with Spring Bayou, as explained by Cooper in a personal written communication with Heath (1954).

AQUIFERS

The aquifers in the Middle Gulf area are the shallow aquifer and the Floridan aquifer.

SHALLOW AQUIFER

The saturated coarser grained surficial deposits overlying the limestone constitute an aquifer that receives water almost entirely from local precipitation. The exception is recharge from artesian seepage and springs and from man's activities and works, including irrigation and effluent from septic tanks and cesspools. The depth to water in the shallow aquifer averages less than 8 feet, and in much of the area is less than 3 feet below land surface.

The slope of the water surface is controlled by the permeability of the water-bearing materials, saturated thickness of the deposits, and local variations in recharge and discharge. Rises in water level are caused by recharge by rainfall, and declines in water level are caused by seepage into streams, lakes, and canals, by evapotranspiration, by leakage induced by pumpage from wells, and by natural leakage into the Floridan aquifer.

The general shape of the water surface in the shallow aquifer for a high-water period August – November 1965, and a low-water period May 1966, are shown in figures 22 and 23. The August-November map represents a period when water levels are at seasonal highs, and the May map represents a period when water levels are at or near seasonal lows.

The direction of movement of the water is down-gradient and normal to the contour lines. The water moves generally westward in the northern part of the area and south to southwestward and southeastward in the southern part. The slope of the shallow water table is about the same as the slope of the stream channels in the area, and the configuration of the water table is similar to that of the land surface and that of the potentiometric surface of the Floridan aquifer.

The water level in the shallow aquifer ranges from slightly below to as much as 17 feet above the water level in the Floridan aquifer. Throughout much of the area, water moves downward from the shallow aquifer and recharges the Floridan aquifer. However, locally around upper Old Tampa Bay and southeast of New Port Richey, the

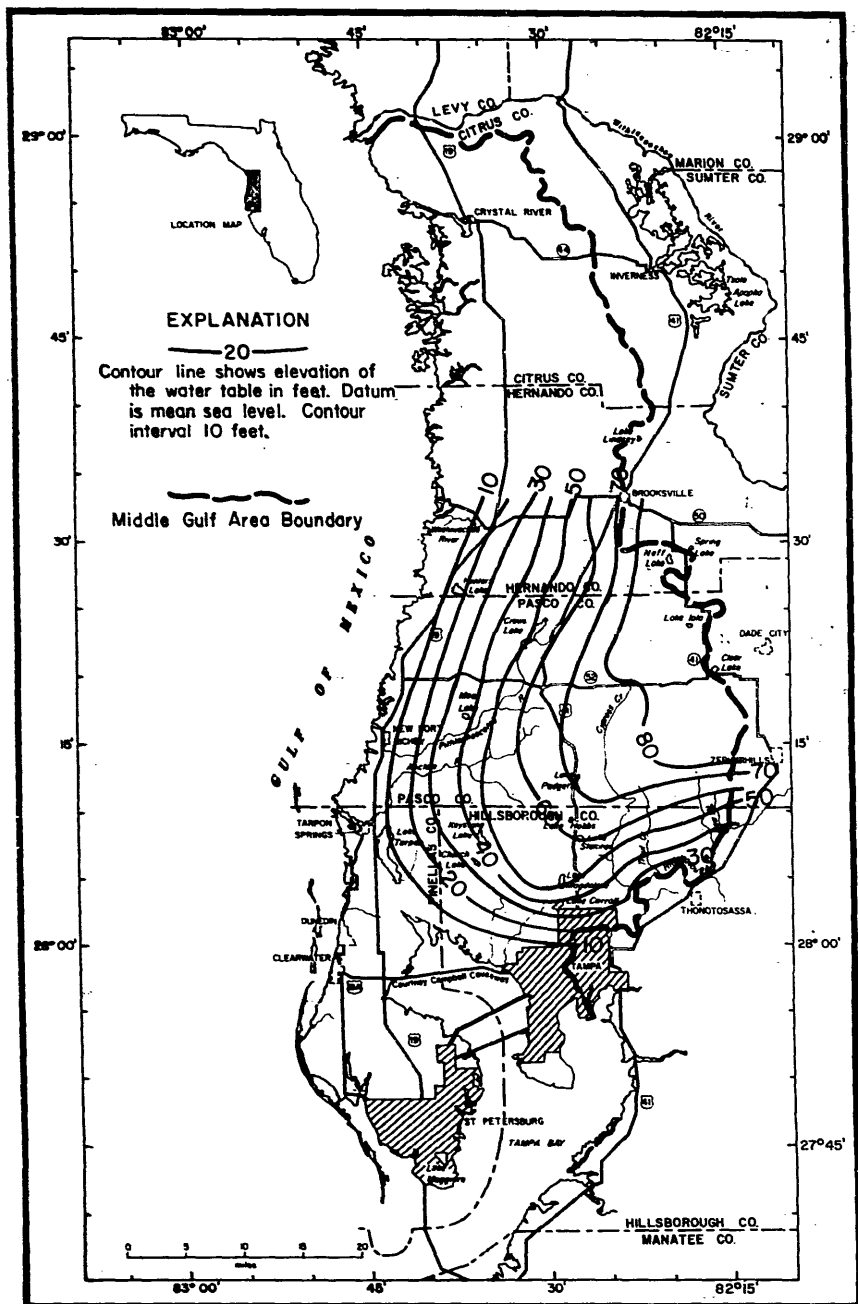


Figure 22. Map of Middle Gulf area showing contours of water levels in the shallow aquifer during a period of high water levels, August-November 1965

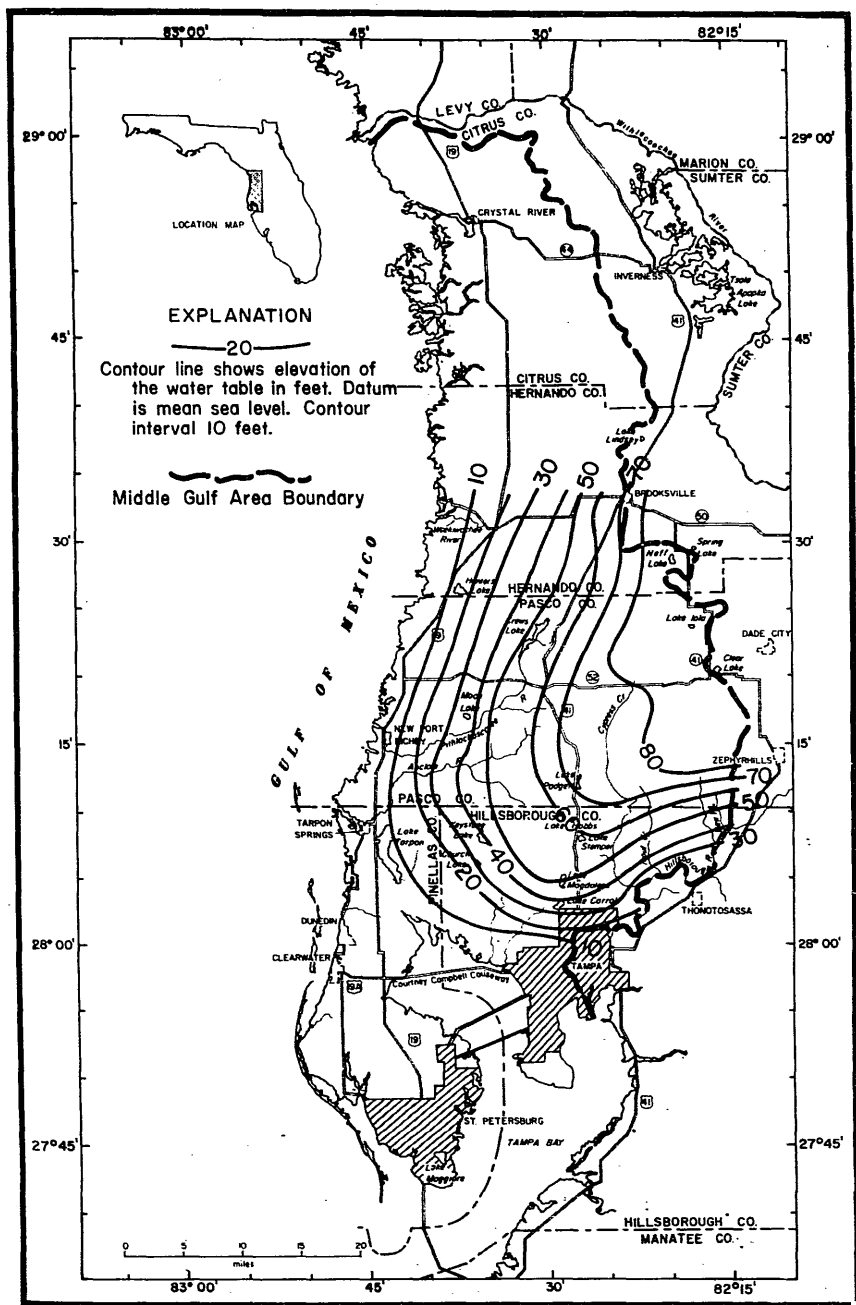


Figure 23. Map of Middle Gulf area showing contours of water levels in the shallow aquifer during a period of low water levels, May 1966

water level in the shallow aquifer is lower than the level in the Floridan aquifer and water flows upward to the shallow aquifer. In the northern part of the area no apparent head difference exists between the shallow and Floridan aquifers. The greatest difference occurs in the well fields in the southern part, and in the topographically higher Brooksville area.

The shallow aquifer is not at present extensively used as a source of domestic or public supply in the Middle Gulf area. Currently its most extensive use is for lawn irrigation.

The hydrographs of the water levels in the shallow aquifer in the southern part of the area and rainfall records at a nearby station are shown in figure 24. The highest water levels generally occur in July and August, the wettest months, and the lowest in late May or early June just prior to the rainy season.

Undisturbed samples of sediments comprising the shallow aquifer were collected at twelve sites at depths ranging from 1 foot to 9 feet and at two sites from depths of 10 to 42 feet in the Middle Gulf area figure 25. Selected samples of shallow aquifer materials were analyzed for permeability, porosity, specific yield, and particle-size distribution. The analyses were made by the Hydrologic Laboratory, U. S. Geological Survey, Water Resources Division, Denver, Colorado. Table 1 shows the results of the tests.

The coefficient of permeability ranged from 0.001 gpd per ft² (gallons per day per square foot) at sampling sites 5 to 13 miles northwest of Brooksville to 210 gpd per ft² 10 miles west of Brooksville. The porosity ranged from 32 to 45 percent and averaged 39 percent. The specific yield averaged about 29 percent. These values indicate that although the shallow material has a relatively low permeability, the storage capacity is large and the volume of water that will drain from the material, given enough time, is large.

Table 1 shows the specific retention, porosity, specific yield and the permeability for samples collected at 13 sites in the area. This table indicates that permeability in the area is highly variable. The permeabilities are greatest near the surface of the ground and generally decrease with depth. For example, the permeability of samples 13 to 13C decreased from 77 to 5 gpd per ft² in the depth interval 1 foot to 8½ feet; samples 10 to 10C decreased from 110 to 6 gpd per ft² in the depth interval 1 foot to 6 feet; and samples 4A to 4C decreased from 49 to 0.002 gpd per ft² in the depth interval 3 to 6 feet. Samples 6 to 6A collected east of Weekiwachee Springs and samples 7 to 7C collected near the Hernando-Pasco County line did not show any significant changes in permeabilities at depths of 1 foot to 9 feet.

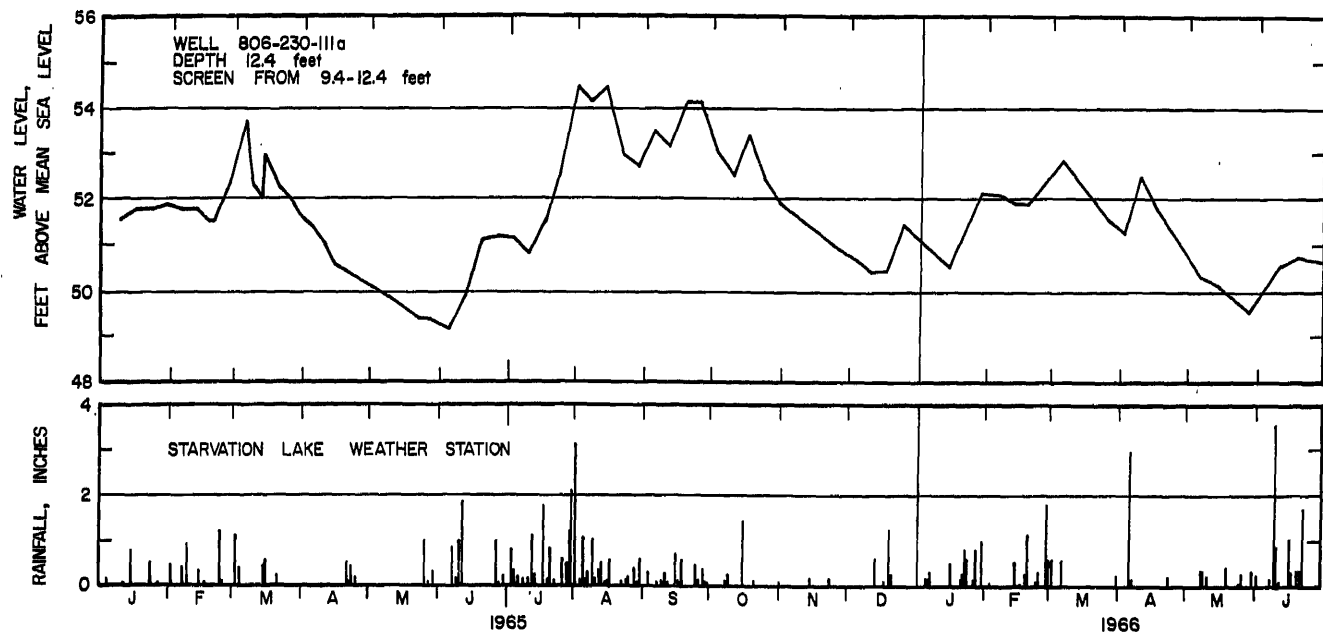


Figure 24. Graph showing rainfall at Starvation Lake weather station, and water-level fluctuation in the shallow aquifer in the southern part of the Middle Gulf area, January 1965 -- June 1966

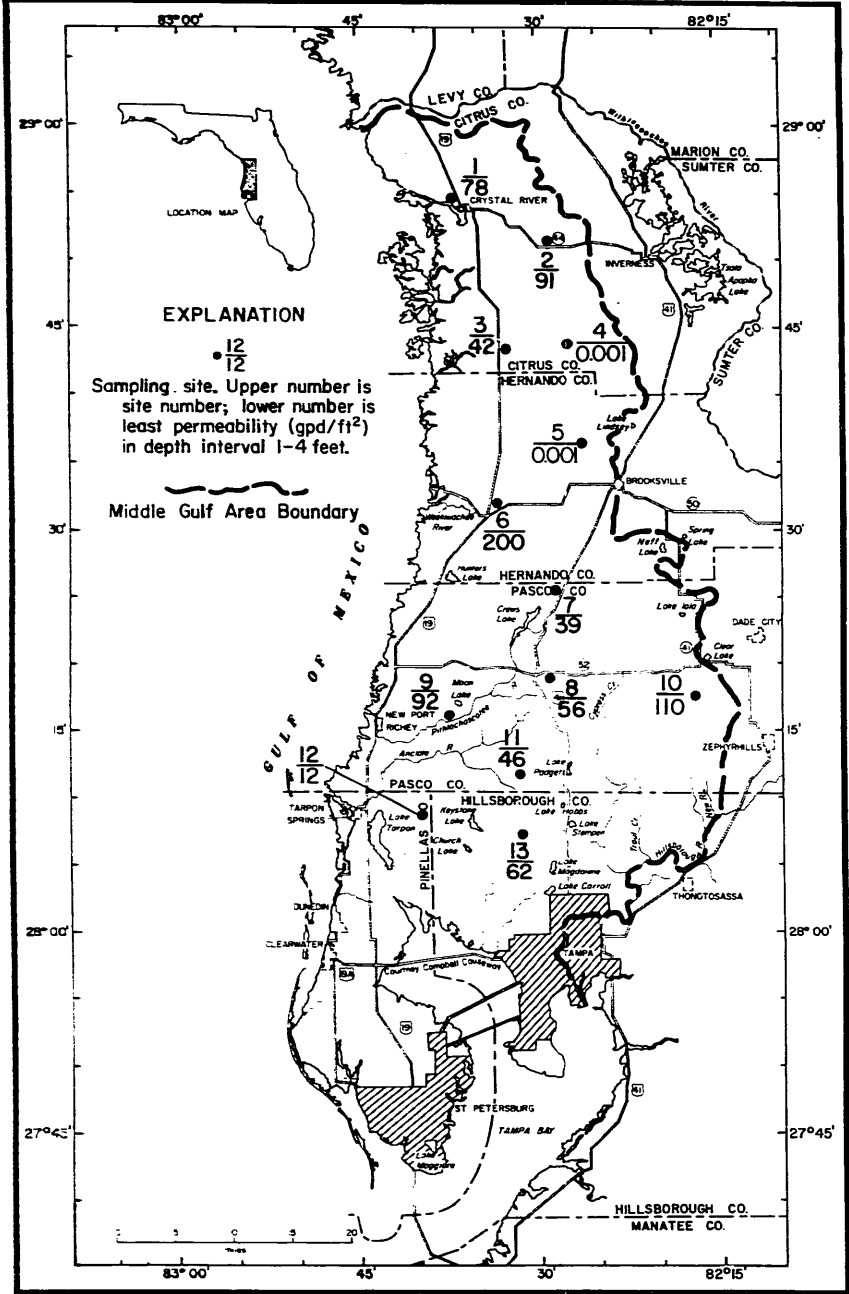


Figure 25. Map showing location of sediment sampling sites and permeabilities of selected samples in the Middle Gulf area

Table 1. — Laboratory analysis of unconsolidated sediment samples
(Analysis by U. S. Geological Survey Hydrologic Laboratory, Denver, Colorado)

Sampling site	Depth (feet)	Specific retention (percent)	Total porosity (percent)	Specific yield (percent)	Coefficient of permeability (gpd per ft ²)
1	1.0-1.2	6.8	38.4	31.6	78
2	3.0-3.2	-	-	-	91
3	2.0-2.2	8.6	45.5	36.9	42
4	1.0-1.2	-	-	-	.001
4a	2.8-3.0	-	-	-	49
4b	3.8-4.0	-	-	-	.1
4c	6.0-6.2	28.6	32.5	3.9	.002
5	3.0-3.2	38.4	45.5	7.1	.001
6	4.0-4.2	-	-	-	200
6a	9.0-9.2	2.0	35.7	33.7	210
7	0.9-1.1	-	-	-	39
7a	3.1-3.3	-	-	-	56
7b	6.0-6.2	-	-	-	43
7c	8.0-8.2	3.7	36.0	32.3	44
8	2.5-2.7	3.4	40.2	36.8	56
9	1.0-1.2	-	-	-	92
9a	6.0-6.2	2.8	34.7	31.9	66
10	0.8-1.0	-	-	-	110
10a	3.0-3.2	-	-	-	150
10b	4.5-4.7	-	-	-	74
10c	6.0-6.2	7.7	35.6	27.9	6
11	3.0-3.2	2.5	32.2	29.7	46
12	4.0-4.2	4.9	34.9	30.0	12
12a	10-12	4.9	36.1	31.2	180R/
12b	20-22	4.0	37.2	33.2	180R/
12c	30-32	9.0	43.2	34.2	67R/
12d	40-42	8.5	44.4	35.9	17R/
13	1.0-1.2	-	-	-	77
13a	3.0-3.2	-	-	-	62
13b	5.2-5.4	-	-	-	6
13c	8.5-8.7	11.1	38.4	27.3	5
13d	10-12	8.2	45.5	37.3	40R/
13e	20-22	5.6	37.1	31.5	190R/
13f	30-32	10.1	42.2	32.1	67R/

R/Repacked samples

FLORIDAN AQUIFER

The Floridan aquifer, one of the most productive in the world, underlies the Middle Gulf area. This aquifer supplies virtually all ground water used in the area, feeds some of the largest fresh-water springs in the world, and is the conveying unit by which most of the water moves through the area. The aquifer is composed of a number of thick permeable zones which more or less function as a single water conveying and water storage unit within several geologic units. These units consist of more than 1,000 feet of limestone and dolomite and in descending order from younger to older include the lower part of the Hawthorn Formation, the Tampa Formation, the Suwannee Limestone, the Ocala Group (Crystal River Formation, Williston Formation, and Inglis Formation), the Avon Park Limestone, and the upper part of the Lake City Limestone. In most areas the upper predominantly sandy and clayey part of the Hawthorn Formation is included in the shallow aquifer.

Zones of different permeability occur within the aquifer. Some zones yield large volumes of water whereas others yield little water. The most productive zones are: (1) the uppermost limestone (Hawthorn Formation or Tampa Formation) that directly underlies the surficial sand and clay deposits; (2) the lower part of the Suwannee Limestone; (3) the Avon Park Limestone below the top 100 feet; (4) and the upper part of the Lake City Limestone.

The depth to the top of the Floridan aquifer differs throughout the area. In this report, the top of the aquifer is taken to be the top of the first consistent limestone, figure 26. The highest elevation of the aquifer top is in the eastern part of the area and the lowest elevation is in the southern part near the coast. In the western third of the area, the top of the aquifer is below mean sea level.

Figures 27 and 28 show the elevation of water levels in the Floridan aquifer during August – September 1965 and May 1966. The configuration of the contours was about the same in September as in May although the September water levels were about 2 feet higher.

These illustrations also show the mean sea level contour (zero contour on maps) near the coast. The exact position of the mean sea level contour is not well defined and its location was extrapolated from the spacing of the next two up-gradient contours. The position of this contour inland will markedly affect the hydrology of the inland area and the hydrochemistry of the aquifer. Where this zero water level lies inland, offshore outflow from the aquifer is negligible and discharge from the aquifer takes place inland from the zero contour.

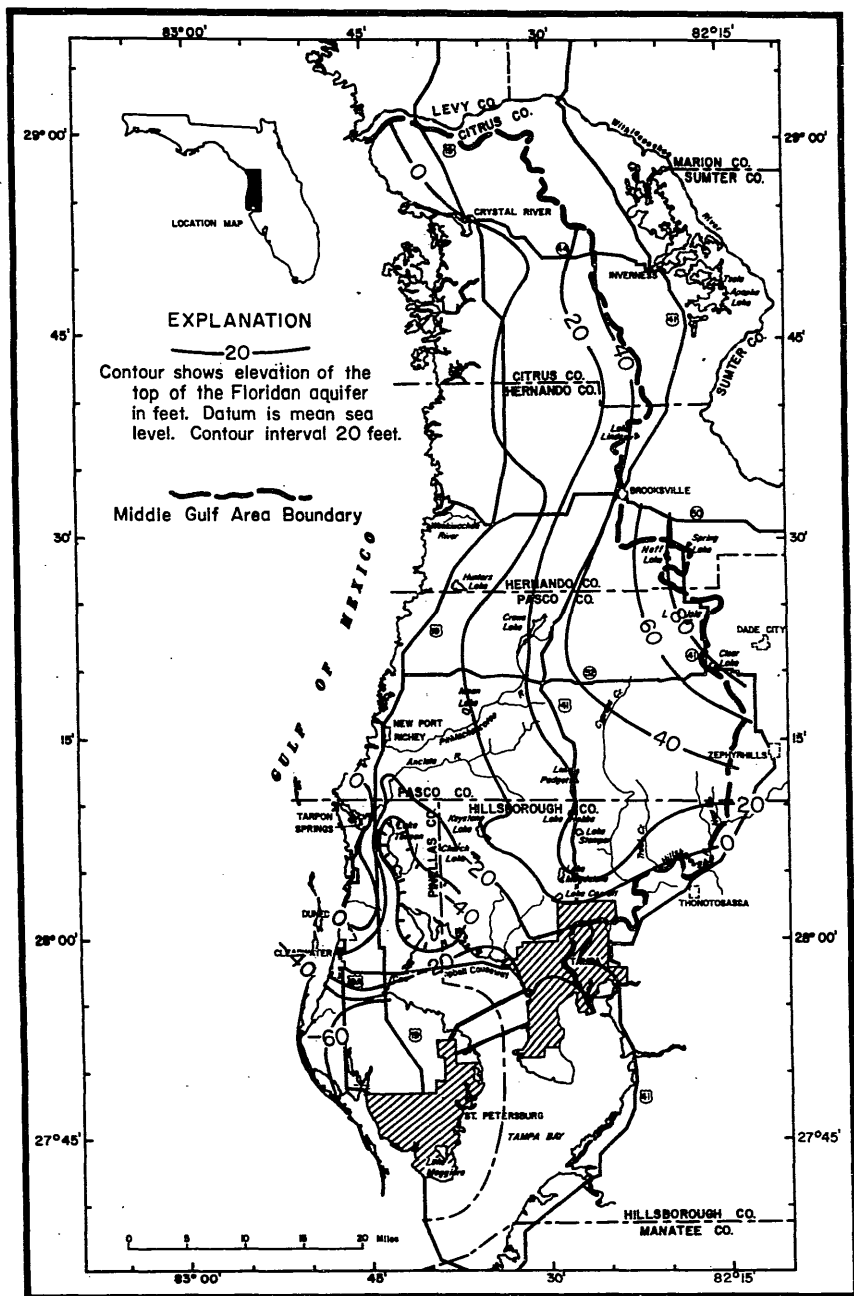


Figure 26. Map of Middle Gulf area showing contours on top of the Floridan aquifer

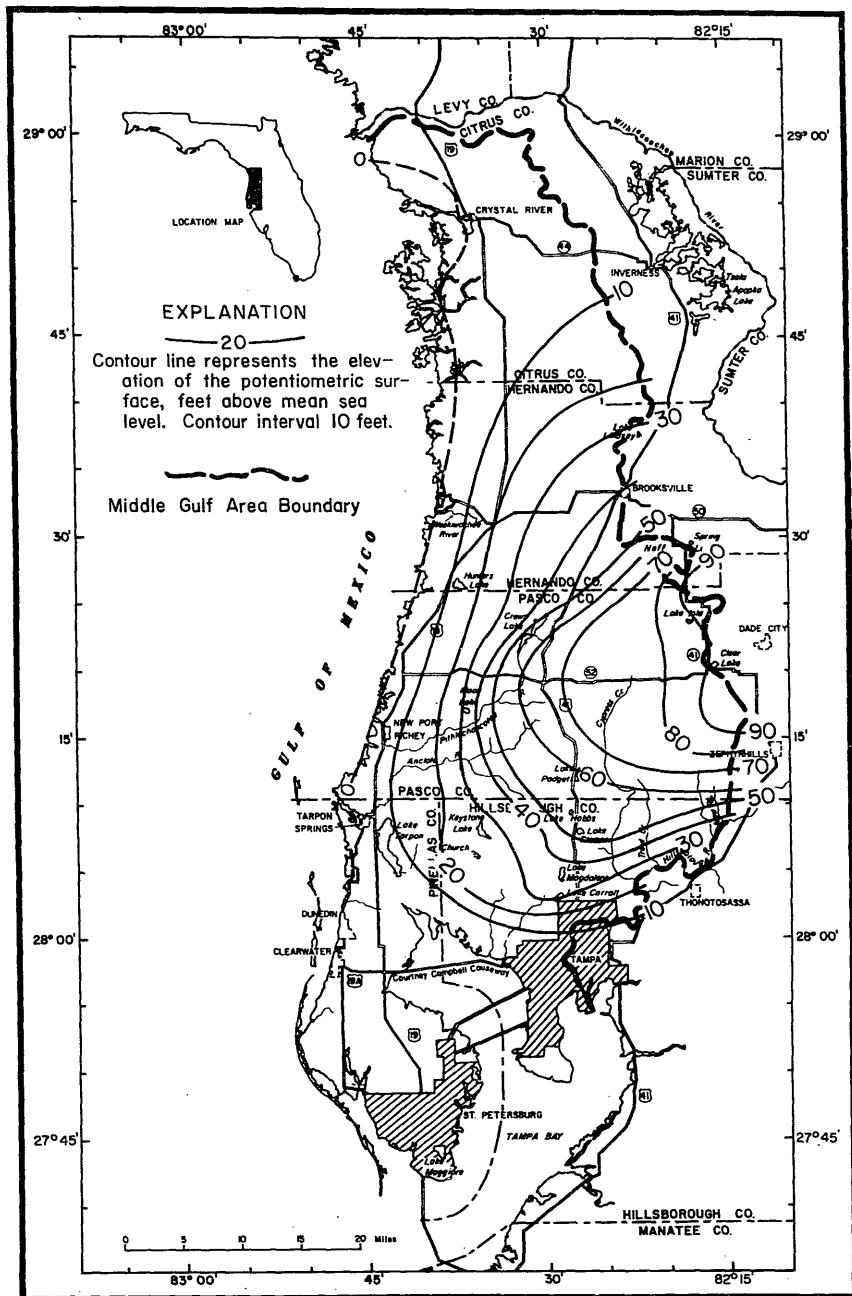


Figure 28. Map of Middle Gulf area showing contours of water levels in the Floridan aquifer during a period of low water levels, May 1966

Recharge to the Floridan aquifer occurs wherever geologic and hydrologic conditions are favorable for water to move into the aquifer. Recharge is not restricted to areas of high water levels (as for example, the Pasco high). A substantial part of the recharge occurs over the entire area through permeable material overlying the aquifer, through sinkholes, and from streams and lakes.

Water tends to move perpendicular to and toward contours of progressively lower elevation. The general direction of water movement in the Floridan aquifer in the Middle Gulf area is from east to west, but in the southern part of the area movement is south to southwest.

Discharge from the Floridan aquifer occurs as (a) seepage or spring flow into streams; (b) pumpage from wells; (c) ground-water outflow; and (d) evapotranspiration in areas where the aquifer is at or near land surface.

A water balance was determined for the Floridan aquifer in the southern part of the area and is discussed in detail in a later section.

Water-level fluctuations. — The volume of water in the aquifer varies with changes in the amount of recharge and discharge. When recharge exceeds discharge, the water in storage increases and the water levels rise; conversely, when discharge exceeds recharge, the water in storage decreases and water levels decline. Thus, water-level fluctuations are an index to seasonal and long-term changes in storage.

The hydrographs of wells penetrating the Floridan aquifer in the Middle Gulf area shown in figure 29 illustrate seasonal and long-term changes in water levels. The highest water levels generally occur in September and October following the rainy season and the lowest water levels occur in May, just preceding the rainy season. The patterns of seasonal water-level fluctuations generally are similar throughout the Middle Gulf area except for those wells in or near heavily pumped areas. The greatest range in water-level fluctuations occurs in the eastern part of the Middle Gulf area and in an area of heavy pumping north of Tampa; the smallest fluctuations occur in the western part of the area, figure 30.

Long-term water-level records of two wells (808-245-424 and 815-226-112) within 5 to 11 miles of three large well fields in northwest Hillsborough and northeast Pinellas counties do not show any noticeable declines in water levels as a result of large ground-water withdrawals from the fields, figure 31. This indicates that noticeable regional declines have not occurred. However, long-term records for a well (807-230-433) in the cone of depression caused by pumping in St.

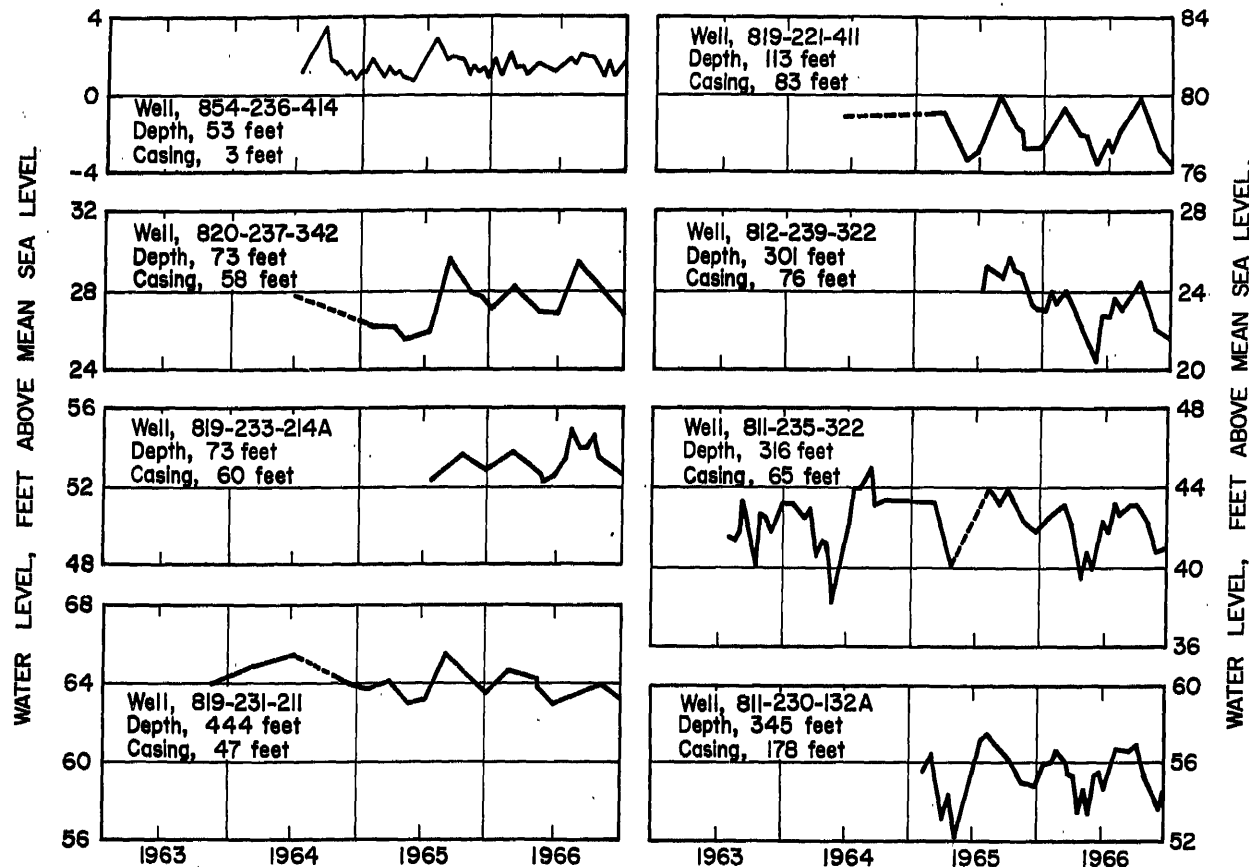


Figure 29. Hydrographs showing seasonal changes in water levels in the Floridan aquifer

Petersburg's Section 21 well field indicate that water levels have declined progressively — almost 11 feet — since pumping began at the well field in February 1963. This continuous decline indicates that the cone of depression is still expanding and that vertical leakage from the shallow aquifer is not yet sufficient to support the withdrawal. Therefore, the lateral extent of the cone of depression will continue to expand with increases in pumping rates.

Ground-water withdrawals in the well-field areas increased from about 3 mgd in 1930 to about 45 mgd in 1966.

Hydrographs of paired shallow and deep wells in Pasco County are shown in figure 32. Water levels in the deep well (depth 150 ft.) are representative of water levels in the Floridan aquifer and water levels in the shallow well (depth 9 ft.) are representative of water levels in the shallow aquifer. Both wells respond rapidly to rainfall, and the patterns of water-level fluctuation are similar, thus indicating good hydraulic connection between the aquifers.

Hydraulics of the aquifer — The transmissivity of the Floridan aquifer in the coastal area north of the Pasco-Hernando County line was determined from the equation $Q = TIL$. The average hydraulic gradient in the Floridan aquifer for a 37-mile section extending from a point north of the town of Crystal River nearly to the Citrus-Hernando county line was about $1\frac{1}{2}$ feet per mile. The total discharge of water in this area was about 1,300 cfs (840 mgd), which included the flow of Crystal River, Homosassa Springs, and Chassahowitzka River. Transmissivity of the aquifer was 15 mgd per foot. Using the same method, the transmissivity was also computed for an 18-mile section extending south of the Hernando-Citrus county line to south of the Hernando-Pasco county line. This section included the Weekiwachee Springs area. The hydraulic gradient in the section averaged about 2 feet per mile, and the flow of the Weekiwachee averaged 300 cfs (194 mgd). The computed transmissivity was about 5 mgd per foot. These large transmissivities of the aquifer were reflected by the large spring discharges along the northern part of the Middle Gulf area.

A number of aquifer tests were made in the Southern part of the Middle Gulf in Pinellas and Hillsborough counties to determine the hydrologic properties of the Floridan aquifer. Analyses of these tests indicated that the coefficient of transmissivity of the aquifer in the southern part of the area ranged from 165,000 to 550,000 gpd per ft. and the coefficient of storage from 0.002 to 0.007.

Analyses of data in engineering reports by Black and Associates, and Briley, Wild and Associates (1952, 1954) for aquifer tests at the

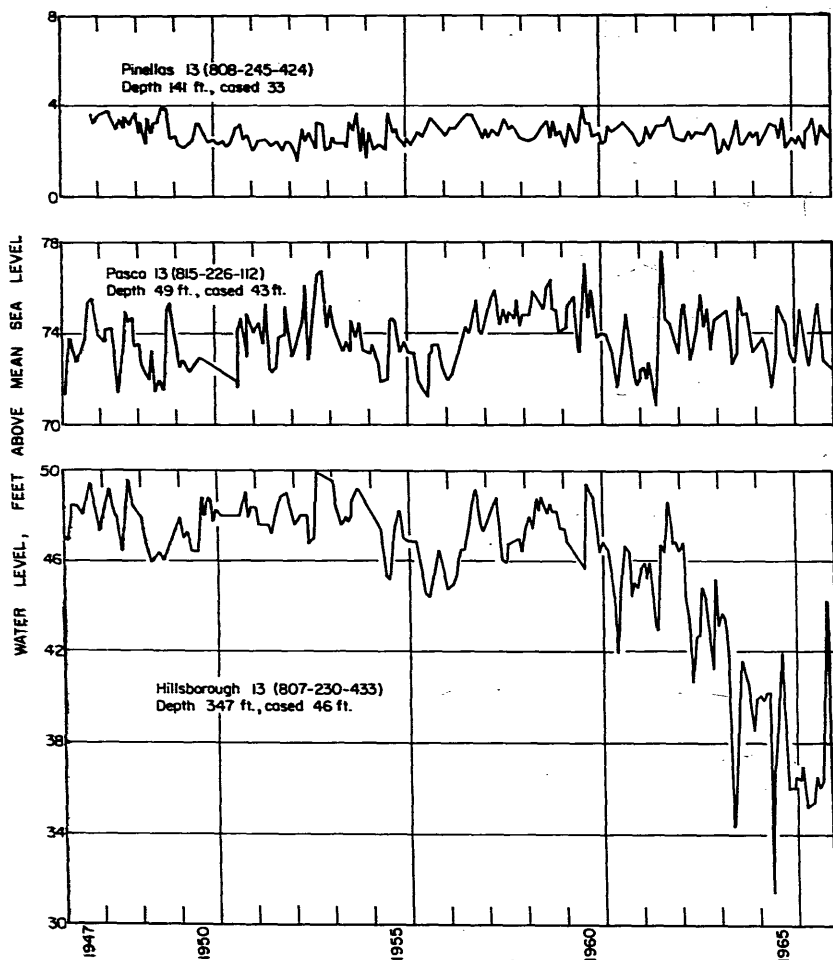


Figure 31. Hydrographs showing long-term water-level records for wells in Middle Gulf area

Eldridge-Wilde field indicated that the vertical movement of water through the overlying sediments was detectable within less than a day. A leakage factor P'/m' (where P' is the coefficient of vertical permeability of the confining bed and m' is the thickness of the bed) was determined to be about 2×10^{-3} gpd per ft³. The quantity of water recharging the Floridan aquifer based on a head differential of 10 feet was computed to be 560,000 gpd per square mile, and based on a head differential of 15 feet on May 19, 1966, was about 840,000 gpd per square mile.

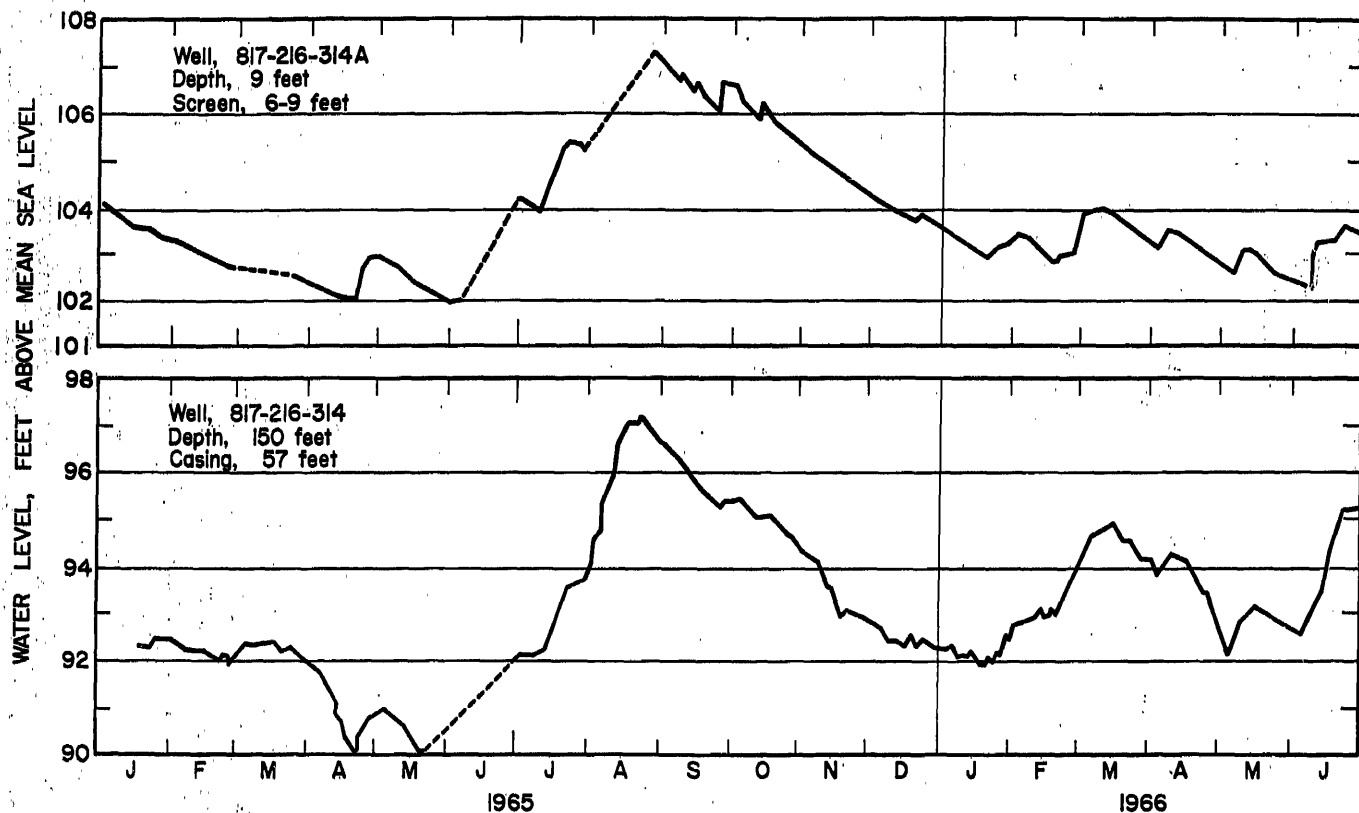


Figure 32. Hydrographs showing water-level fluctuations in paired shallow and deep wells, Pasco County

A 3-day test at the Section 21 well field indicated that the permeability of the materials overlying the Floridan aquifer was small. Data collected by Leggette, Brashears, and Graham (1966) during a long-term test at the well field indicated that leakage occurred within about 11 days. The leakage factor (P'/m') computed from the test was about 1.5×10^{-3} gpd per ft³. Based on this value of P'/m' , recharge to the Floridan aquifer by leakage from the shallow aquifer ranged from about 590,000 to about 670,000 per square mile.

Figures 33 and 34 show time-drawdown graphs based on values of transmissivity, storage, and leakage obtained at the Eldridge-Wilde and the section 21 fields. For example, at the Elridge-Wilde field the drawdown in a well 100 feet from a well being pumped at 1,000 gpm for 100 days is about 6.6 feet, and at a distance of 1,000 feet the drawdown would be about 3 feet. Estimated water-level declines for any pumping rate can be determined from the curves because the drawdowns are directly related to the rate of pumping. Thus, if the pumping rate is doubled, water-level declines will be double that shown on the curves.

Water quality. — The quality of water in the upper 300 feet of the Floridan aquifer is generally good. The mineral content of the water is less than 500 mg/l except near the coast where the concentration approaches that of sea water. Water that has a mineral content of less than 500 mg/l is usable for most purposes. The mineral content in the inland area is mostly calcium bicarbonate, which causes the water to be alkaline and moderately hard to hard. Other mineral constituents, including silica, potassium, sulfate, sodium, and chloride occur in concentrations generally less than 10 mg/l. Fluoride and nitrate are usually present in concentrations of less than 1.0 mg/l. Analysis of water from selected wells in the Middle Gulf area are presented in Table 2.

Figure 35 shows the mineral content and chloride concentration of water in the Floridan aquifer in the Middle Gulf area. The high mineral content of water in the aquifer near the coast is caused by sea water. Generally water in the area bordering the coast contains chloride in excess of 250 mg/l, especially in wells deeper than 100 feet. Mineralized water occurs at depths greater than 700 feet in the well fields in northwest Hillsborough and northeast Pinellas counties.

WATER BALANCE

The water balance is a method of accounting for the inflow and outflow of a hydrologic system. The balance involves estimating the

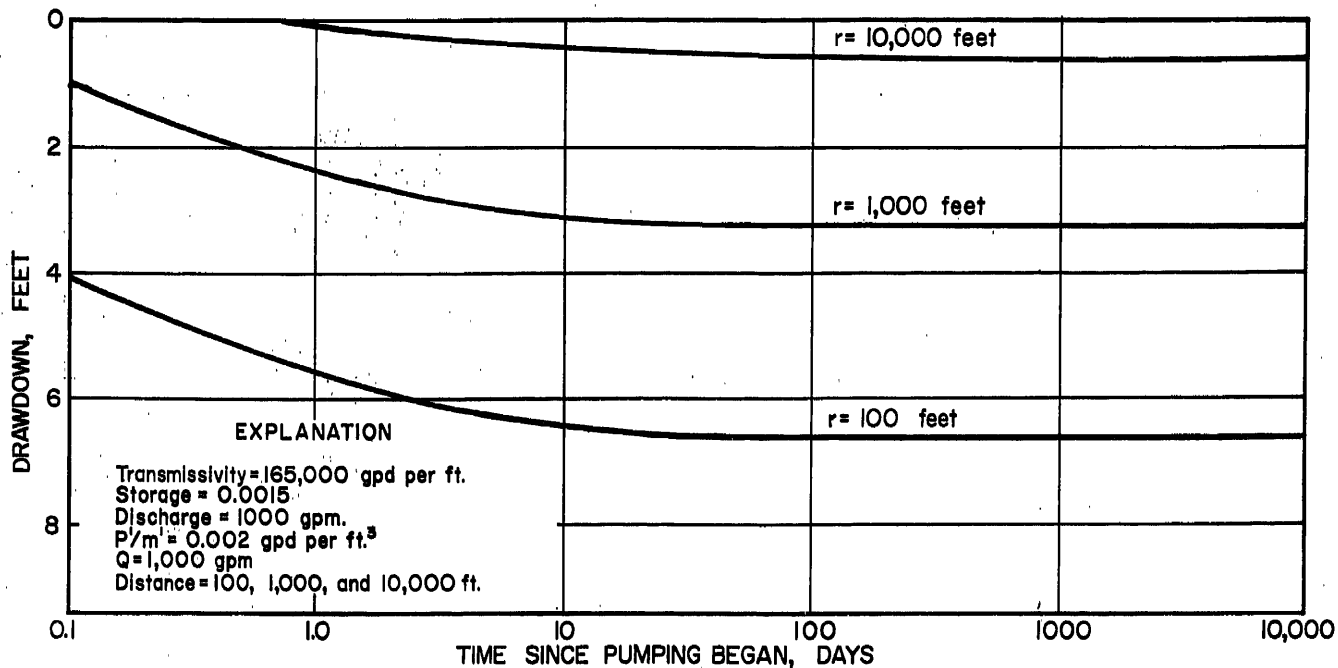


Figure 33. Time-drawdown curves, Eldridge-Wilde well field

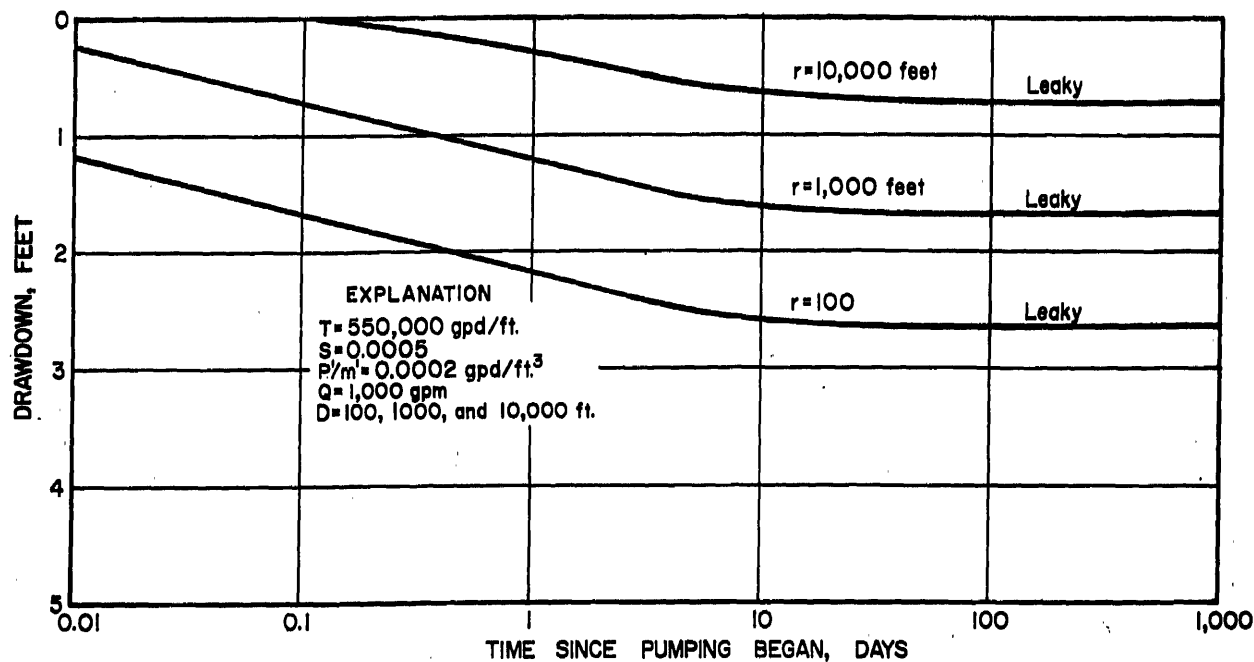


Figure 34. Time-drawdown curves, Section 21 well field

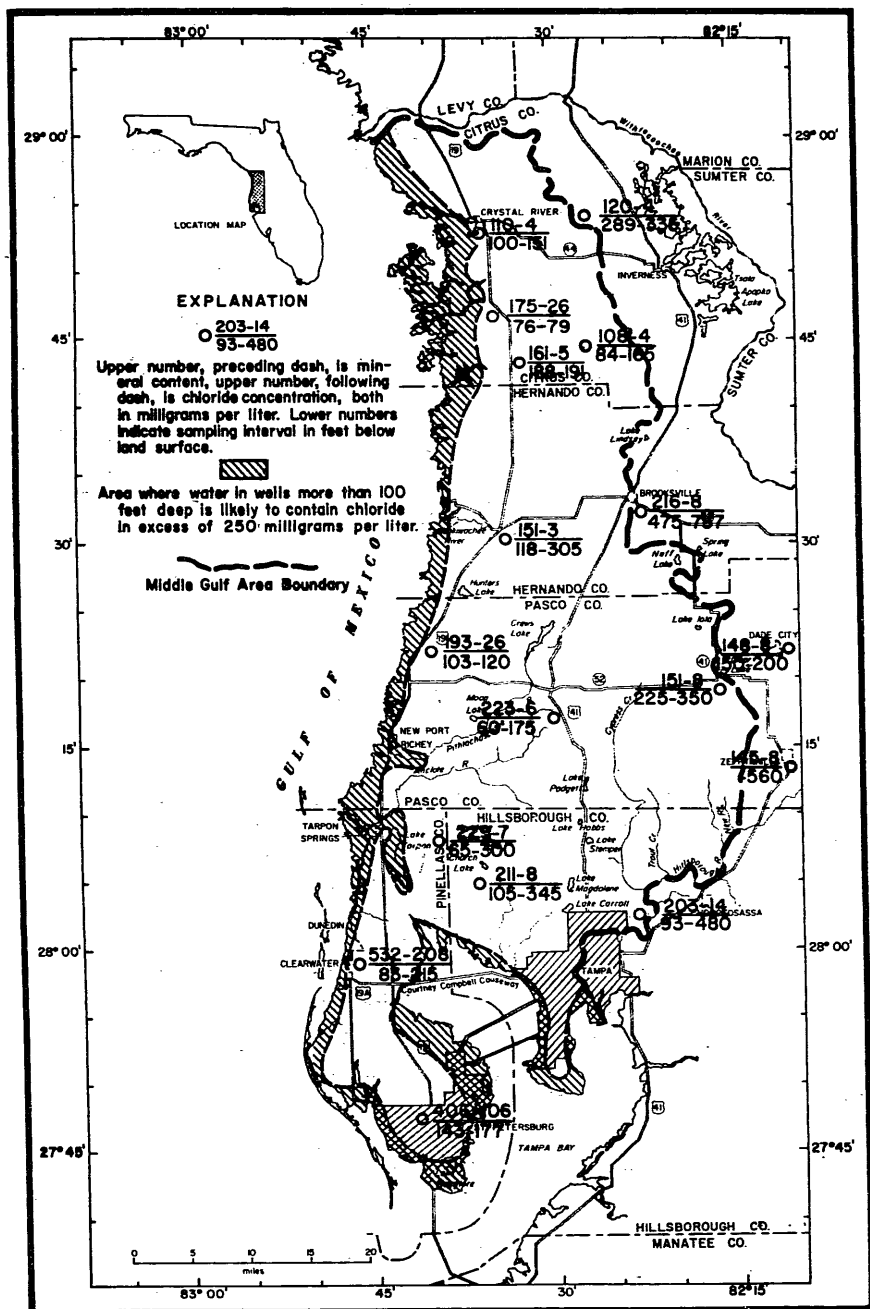


Figure 35. Map of Middle Gulf area showing mineral content and chloride concentration in the Floridan aquifer

TABLE 2. ANALYSES OF WATER FROM SELECTED WELLS IN MIDDLE GULF AREA (Chemical constituents are expressed in milligrams per liter)

Well Number	Date of collection	Depth of well (feet)	Depth of casing (feet)	Aquifer sampled	Depth of sample (feet)	Temperature (°C)	Temperature (°F)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)
748-242-122	2-10-65	177	144	F	144-177	23.4	74	0.17	91	15
757-246-232	2-10-65	215	83	F	83-215	24.5	76	.78	94	12
805-235-114	2-9-65	354	105	F	105-354	24.8	77	.13	68	3.5
808-240-211	2-11-65	300	65	F	65-300	24.0	75	.21	70	5.7
814-210-334	2-24-65	560	90	F	90-560	24.4	76	.07	46	1.2
820-216-423	2-16-65	350	225	F	225-350	23.4	74	.82	46	3.2
821-211-213A	2-24-65	200	150	F	150-200	23.4	74	.03	43	4.5
822-240-411	2-17-65	120	103	F	103-120	23.8	75	.08	55	4.6
832-223-212	2-4-65	757	300	F	300-757	22.8	73	.12	62	10
843-233-424	8-2-65	176	166	F	166-176	26.3	79	.00	44	8.7
845-217-334	2-4-65	212	190	F	190-212	23.2	74	.25	40	2.4
847-234-313	2-3-65	79	76	F	76-79	23.6	74	.30	37	7.7
853-235-211	2-3-65	152	100	F	100-152	23.2	74	.24	28	5.4
855-227-243A	2-2-65	295		F	-295	23.4	74	.12	33	2.3

Sodium (Na)	Potassium (K)	Carbonate (CO ₃)	Bicarbonate (HCO ₃)	Sulfate (SO ₄)	Chloride (Cl)	Fluoride (F)	Nitrate (NO ₃)	Dissolved solids (residue at 180°C)	Hardness as CaCO ₃		Specific conductance (Micromhos at 25°C)	pH	Color
									Calcium, magnesium	Noncarbonate			
31	2.5	0	236	13	106	0.3	0.1	406	288	94	689	7.7	5
88	1.7	0	209	14	208	.4	.0	532	284	112	975	7.7	1
5.9	0.9	0	222	2.4	8.0	.2	.1	211	184	2	349	7.8	6
6.5	1.2	0	244	5.8	7.0	.2	.1	229	198	0	370	7.9	5
5.3	.3	0	136	3.6	8.0	.2	4.9	145	120	8	249	7.5	1
4.9	.9	0	143	6.2	8.0	.1	2.5	151	128	11	258	7.7	0
4.5	.2	0	134	11	8.0	.2	1.6	148	126	16	250	7.7	1
15	.9	0	167	3.0	26	.1	.0	193	156	19	331	7.8	0
5.6	.5	0	221	11	8.0	.2	.0	216	196	15	360	7.7	0
3.7	.4	0	168	7.2	5.0	.3	.0	161	146	8	290	7.3	0
5.6	.6	0	129	2.4	7.0	.1	.2	127	110	4	225	7.7	10
16	1.1	0	142	9.2	26	.2	.0	175	124	8	309	7.9	4
2.8	.4	0	94	15	4.0	.2	.0	110	92	15	182	7.9	3
2.2	.3	0	111	.4	3.0	.1	.0	104	92	1	178	7.9	0

quantities of water involved in each component of inflow and outflow parameters for a given period. Each component taken into consideration in the balance is given in the equation below:

$$P + SI + GI - R - ET - GO = \Delta S \quad (1)$$

where P = Precipitation, inches

SI = Surface-water inflow, inches

GI = Ground-water inflow, inches

R = Runoff, inches

ET = Evapotranspiration, inches

GO = Ground-water outflow, inches

ΔS = Change in storage, inches

The Middle Gulf area is delineated by a topographic divide. Therefore, surface-water inflow to the area is zero. Precipitation, runoff, and ground-water outflow can be measured or estimated with reasonable accuracy. The period of time covered by the calculation can be selected so that the change in storage is practically negligible. This water balance was determined for a 2-year period, June 1964 — May 1966.

A water balance for the Middle Gulf hydrologic system (2,830 sq. mi.) which includes most of the Middle Gulf area and an area to the east of the Middle Gulf area was determined. In determining a water balance the boundaries of the Middle Gulf hydrologic system, figure 36, were selected so that (1) ground-and surface-water inflow from adjacent areas was zero or negligible, (2) the only significant source of inflow was precipitation; and (3) all significant surface-and ground-water outflow was either measured or computed from hydraulic properties of the ground-water reservoir and water levels in the aquifer. The period for the balance was selected so that the net change in storage was negligible. Evapotranspiration was determined as a residual by the balance equation:

$$ET = P - R - GO. \quad (2)$$

ET , thus determined, is an average value for the larger system which can be applied to the Middle Gulf area.

The water-balance equation for the Middle Gulf area, excluding peninsular Pinellas County, is:

$$GI = P - ET - R - GO + \Delta S. \quad (3)$$

A water balance for peninsular Pinellas County was estimated using precipitation, adjusted ET , and by assuming no surface-and ground-water inflow. Most of the streams in the peninsular area have not been

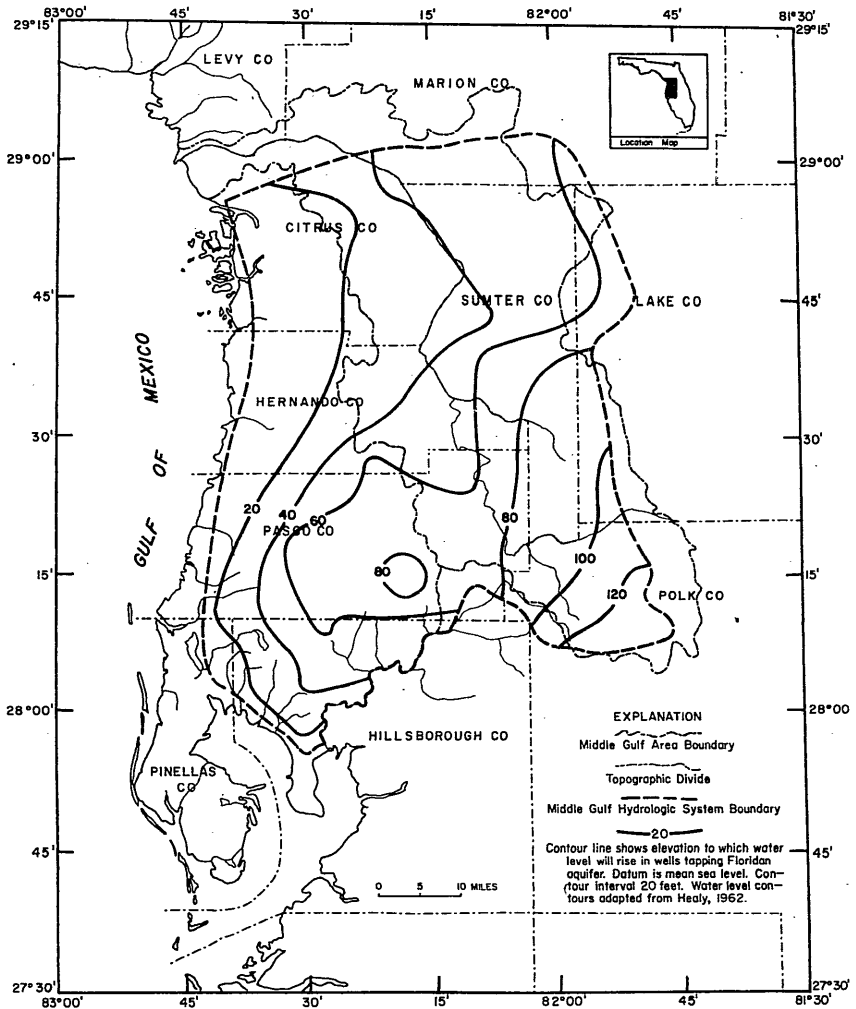


Figure 36. Map showing water levels in wells penetrating the Floridan aquifer, topographic divides, and boundary of the hydrologic system

gaged and data are not sufficient to estimate the ground-water outflow. Therefore, the precipitation minus evapotranspiration was assumed to equal the runoff plus ground-water outflow:

$$P - ET = R + GO. (4)$$

PRECIPITATION

The precipitation used for computations in the water balance was

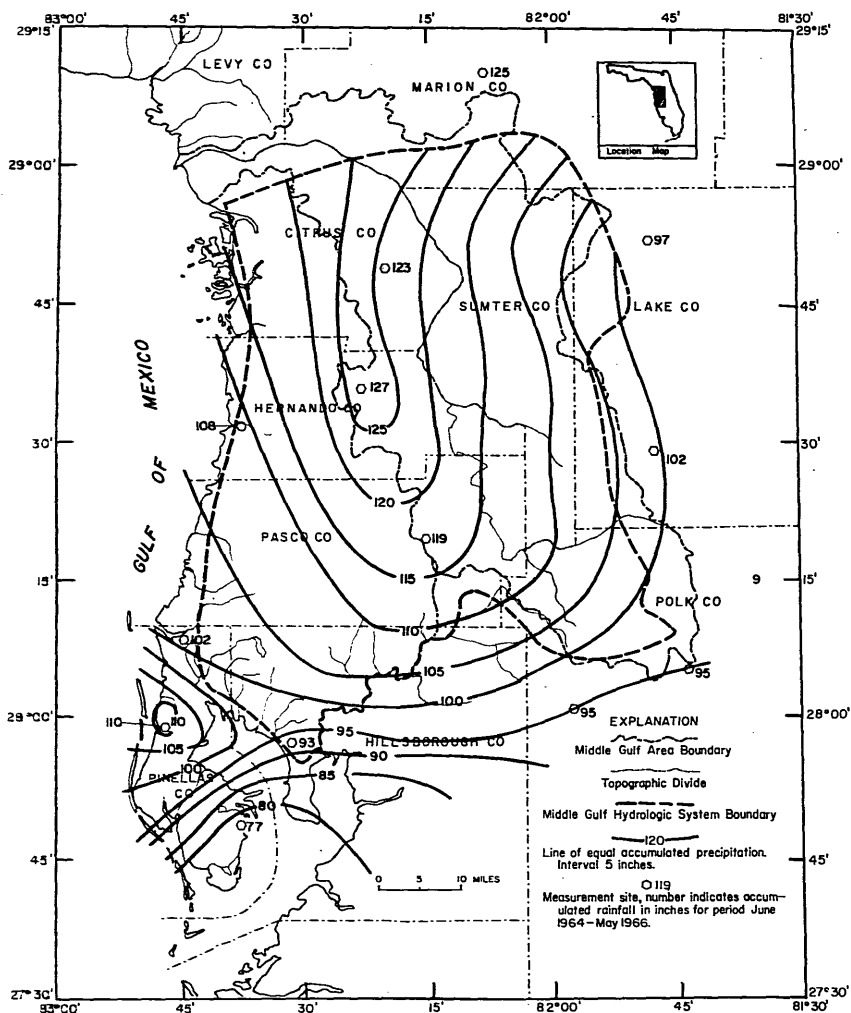


Figure 37. Map showing accumulated precipitation for period June 1964 – May 1966, Middle Gulf hydrologic system

obtained from 14 U. S. Weather Bureau stations. Within the two-year period of the balance, the distribution of the accumulated precipitation varied from 80 to more than 125 inches over the area as shown by the contours on figure 37.

Areal average precipitation was computed using the Thiessen method. The monthly weighted-average precipitation for the Middle Gulf area is tabulated in table 3 and shown on figure 37. The weighted-average accumulation for the Middle Gulf hydrologic system was 114

inches and for that part of the Middle Gulf area included in the total hydrologic system the accumulated precipitation was also 114 inches. The weighted-average accumulation for peninsular Pinellas County was 90 inches.

EVAPOTRANSPIRATION

Evapotranspiration (ET), the discharge of water vapor to the atmosphere, continues as long as open-water or other moist surfaces are exposed to the atmosphere and as long as moisture is available for transpiration by living plants. ET cannot be measured directly for large areas and must be estimated. Therefore, evapotranspiration was obtained as a residual in equation (2). This value is an average for the total system. Local values of ET vary with local climate, soil conditions, and vegetation. Evapotranspiration varies seasonally depending on changes in temperature, vegetative cover, precipitation, and other antecedent conditions which affect soil moisture.

The Thornthwaite method (1955) was used to adjust the average ET for seasonal and areal variations. This method takes into account (1) air temperature, (2) precipitation, (3) hours of sunlight, and (4) the water-holding capacity of the soil and type of vegetation. If water is available to supply the needs of plants and to maintain soil moisture, the combined evaporation from the soil and transpiration through the plants proceeds at a maximum rate referred to as the potential evapotranspiration.

The monthly amounts of actual evapotranspiration for each climatological station were computed by the method outlined by Thornthwaite and Mather (1957). The accumulated monthly value of ET for each climatological station was areally weighted to obtain an average value of ET for the Middle Gulf hydrologic system. The value of ET as determined by the Thornthwaite method for the 2-year balance period was 85 inches as compared with 78 inches as a residual in equation (2). The areally weighted monthly ET values obtained by the Thornthwaite method for each climatological station were adjusted to agree with the average value obtained as a residual in equation (2). The adjusted monthly values are shown in table 5.

RUNOFF

Runoff (R) is defined as that part of the precipitation that occurs in streams (Langbein and Iseri, 1960). It includes water that flows over the ground surface to the streams as well as that which moves through the aquifers and discharges to the streams. For example, the flow of

Crystal River is almost entirely from the Floridan aquifer, and is measured as runoff. About 85 percent of the total runoff from the entire hydrologic system is from this aquifer.

The runoff was computed by distributing the total streamflow over the area of the system and is the most accurately measured item in the water balance. The runoff in terms of water over the Middle Gulf hydrologic system (2,830 sq. mi.) was 36 inches for the 2-year balance period. However, the runoff for that part of the Middle Gulf area (1,110 sq. mi.) in the total hydrologic system, which includes all streams except the Withlacoochee River, was 59 inches for the 2-year balance period, or about 30 inches per year.

A summary of the runoff and streamflow values for each stream, for both the total system and that part of the Middle Gulf area in the total system, is presented in table 3. The location of the streams and the average discharges are shown in figure 38.

GROUND-WATER OUTFLOW

Ground-water outflow is defined as that part of the discharge from the system that occurs through the ground and is estimated to be equal to about 1 inch of water over the system. Nearly all ground-water outflow occurs in the southern part of the area. This estimate was computed using a variation of Darcy's Law, $Q = TIL$, where

- Q is the quantity of water that moves through the aquifer, gallons per day (gpd);
- T is the coefficient of transmissivity, gpd per ft;
- I is the hydraulic gradient, ft. per mile;
- L is the length of the flow section of the aquifer, in feet.

The transmissivities used in the computation ranged from 165,000 to 400,000 gpd per ft. and hydraulic gradients ranged from 3 to 6 feet per mile. Using the above values the outflow along flow sections A, B, C, and D, shown on figure 39, was computed to be 66 mgd or about 2 inches. Of this amount 37 mgd moves westward and southwestward toward the gulf and Old Tampa Bay, 23 mgd moves southwest toward Tampa Bay and Hillsborough River, and 6 mgd moves eastward toward the Hillsborough River.

Because the ground water moves westward through the total system and the middle Gulf area is on the west side of the system, the ground-water outflow (GO) for the total system is discharged from the Middle Gulf area. The outflow for the total system is estimated to be 1 inch, and for the Middle Gulf area 2 inches.

Table 3. — Summary of stream discharge and runoff for total system and Middle Gulf area.

MIDDLE GULF HYDROLOGIC SYSTEM Area-2830 square miles ^a				MIDDLE GULF AREA Area-1110 square miles ^a		
Stream Name	Average Runoff For Period June 1964-May 1966			Average Runoff For Period June 1964-May 1966		
	Cubic feet per second	Million gallons per day	Inches on area	Cubic feet per second	Inches on area	Million gallons per day
Crystal River	900	582	8.65	900	582	22.11
Homosassa River	230	149	2.21	230	149	5.66
Chassahowitzka River	150	97	1.45	150	97	3.72
Weekiwachee River	260	168	2.48	260	168	6.33
Pithlachascotee River	51	33	.48	51	33	1.24
Anclote River	92	59	.88	92	59	2.24
Brooker Creek	25	16	.24	25	16	.61
Rocky Creek	40	26	.38	40	26	.97
Sweetwater Creek	5	3	.05	5	3	.13
Cypress Creek	180	116	1.77	180	116	4.52
Sulphur Springs	45	29	.43	45	29	1.11
Bear Creek	32	21	.30	32	21	.77
New River	14	9	.13	14	9	.34
Busy Branch	7	5	.06	7	5	.17
Trout Creek	73	47	.70	73	47	1.78
Withlacoochee River	1,370	885	13.09			
Withlacoochee-Hills- borough overflow	39	25	.40			
Miscellaneous Springs	310	200	2.97	310	200	7.60
Total	3,823	2,470	36.67	2,414	1,560	59.30

^aDoes not include peninsular Pinellas County and some coastal areas.
See fig. 1 for boundary line.

GROUND-WATER INFLOW

Although the ground-water inflow to the Middle Gulf hydrologic system is zero, the inflow (24 inches) to the Middle Gulf area for the 2-year period was computed as a residual from the water balance equation (3). Most of the ground-water inflow occurs in the northern

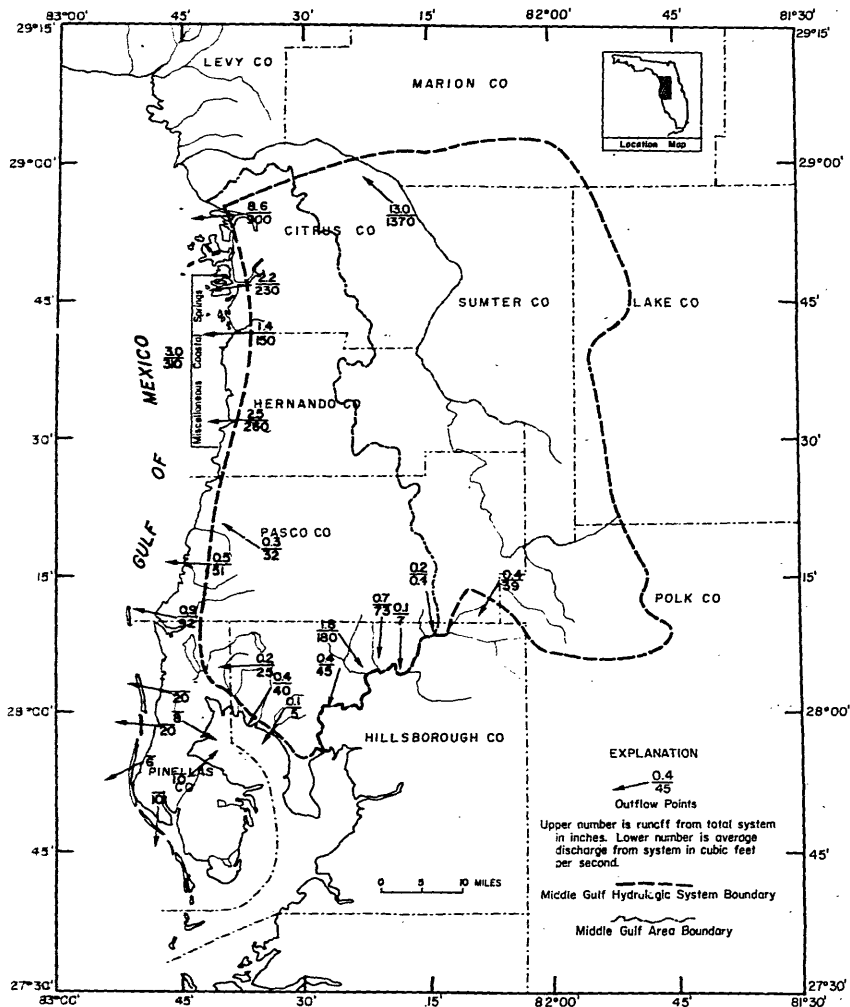


Figure 38. Map showing average stream discharge and runoff for the total Middle Gulf hydrologic system

part of the area as determined from an examination of the map of the potentiometric surface and an analysis of the flow of streams in the Middle Gulf area. A comparison of figures 27 and 28 indicates that

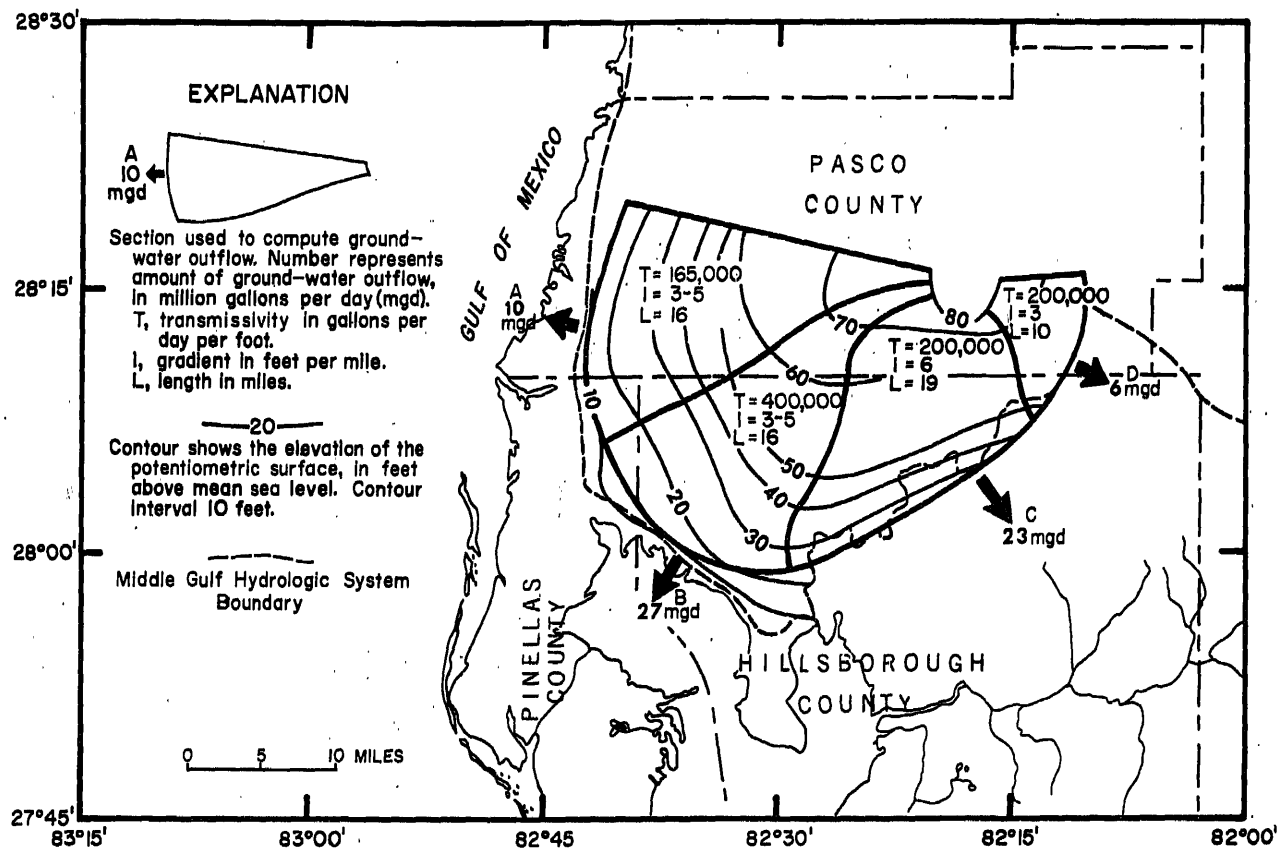


Figure 39. Map of southern part of Middle Gulf area showing flow net for computation of ground-water outflow

ground-water inflow could occur under certain stage conditions in the southern part of the area, because the ground-water divide shifts eastward across the boundary of the Middle Gulf area.

CHANGE IN STORAGE

Water in storage (S) includes that water on the surface (lakes and streams) and in the ground (in the aquifer and soil zone). The change in storage in the Middle Gulf area for the 2-year balance period was insignificant.

The change in storage for the 3-month period June 1965 – August 1965 was equal to an increase of 8.8 inches of water over the area – an increase of 6 billion gallons of water in the Middle Gulf area. During the same period the rainfall and ground-water inflow was 1.03 trillion gallons. The total outflow as evapotranspiration, ground water outflow, and runoff was 773 billion gallons.

ANALYSIS OF THE WATER BALANCE

The monthly variations of precipitation and evapotranspiration for the Middle Gulf area are shown in figure 40. This figure shows that the precipitation and evapotranspiration are highest in summer and lowest in winter. The least precipitation occurs in November and May. Because precipitation greatly exceeds evapotranspiration in the summer, the greatest increase in storage occurs at this time.

The accumulated change in storage (ΔS), which equals $P + GI - ET - R - GO$, for the 2 year balance period, is shown in figure 41. This figure indicates reasonable agreement between the calculated monthly change in storage and the observed storage reflected by end-of-month stages in the various water-conveying components in the Middle Gulf area. A summary of the Values used in the water-balance calculations is presented in table 4.

In summary, the water balance for the total system is:

$$P = ET + R + GO \pm \Delta S \quad (2)$$

$$114 = 77 + 36 + 1 \pm 0,$$

and for that part of the Middle Gulf area in the total system,

$$GI = ET + R + GO - P \pm \Delta S \quad (3)$$

$$24 = 77 + 59 + 2 - 114 \pm 0,$$

and for peninsular Pinellas County,

$$P - ET = R + GO \pm \Delta S \quad (4)$$

$$90 - 69 = 21 \pm 0$$

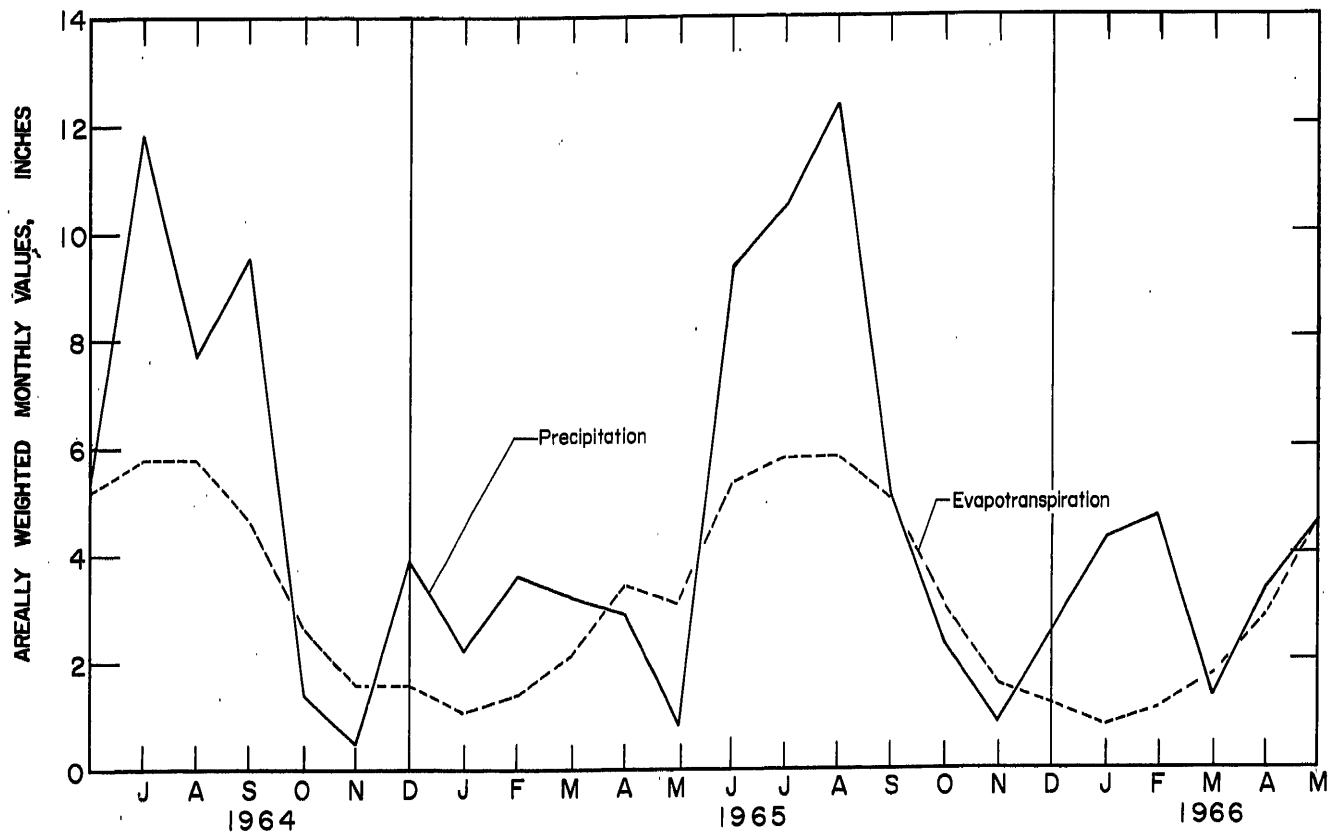


Figure 40. Graph showing monthly variations of precipitation and evapotranspiration in the Middle Gulf area, June 1964-May 1966

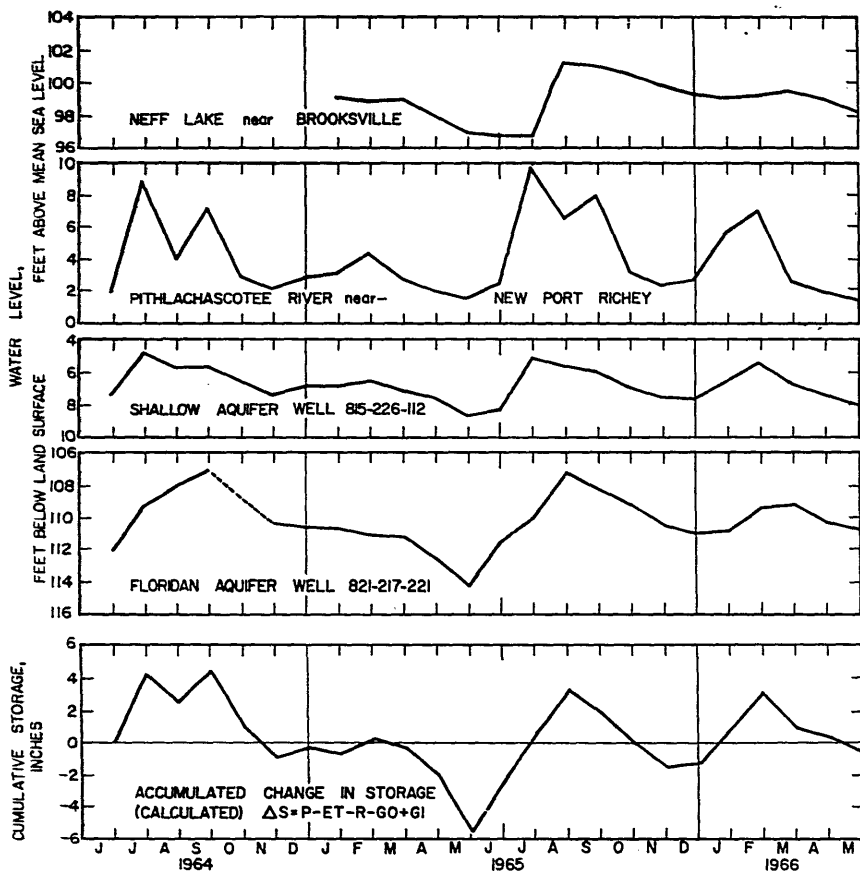


Figure 41. Graph showing monthly accumulated change in storage calculated from water balance and compared with coincident fluctuations of stages of lakes and streams, and water level in aquifers

HYDROLOGIC RELATIONS

The water balance made in this study for the Middle Gulf area has accounted for all inflow and outflow for a 2-year period. The calculations of water in storage at a given time have been compared with actual stages in streams, lakes, and aquifers.

Inflow to any part of the system causes an increase in stage in the system, and outflow causes a decrease in stage. Water levels of streams,

Table 4. — Summary of the water balance for the Middle Gulf area, June 1964-May 1966.

Monthly values in inches; positive except where noted

Precipitation (P): Areally weighted using Thiessen method.

Ground-water inflow (GI): Computed as residual in the water balance for the Middle Gulf area. Prorated on a monthly basis.

Evapotranspiration (ET): Areally weighted using Thiessen method. Computed as a residual in the water balance for the total system. Adjusted areally and seasonally based on the Thornthwaite method.

Runoff (R): Values are monthly summations of runoff.

Ground-water outflow (GO): Computed from flow-net analysis using a variation of Darcy's Law. Prorated on a monthly basis.

Month, Year	INFLOW			OUTFLOW				STORAGE	
	Precipitation (P)	Ground water inflow (GI)	Accumulated inflow	Evapotranspiration (ET)	Run-off (R)	Ground water outflow (GO)	Accumulated outflow	Change in storage (ΔS)	Accumulated change in storage
June, 1964	5.4	1	6.4	5.2	1.3	0.1	6.6	-0.2	-0.2
July	11.8	1	19.2	5.8	2.5	.1	15.0	4.4	4.2
Aug.	7.7	1	27.9	5.8	3.6	.1	24.5	-0.8	3.4
Sept.	9.5	1	38.4	4.7	4.8	.1	34.1	.9	4.3
Oct.	1.4	1	40.8	2.7	2.8	.1	39.7	-3.2	1.1
Nov.	0.5	1	42.3	1.6	1.8	.1	43.2	-2.0	-0.9
Dec.	3.8	1	47.1	1.6	2.4	.1	47.3	.7	-0.2
Jan., 1965	2.2	1	50.3	1.1	2.4	.1	50.9	-0.4	-0.6
Feb.	3.6	1	54.9	1.4	2.2	.1	54.6	.9	.3
Mar.	3.2	1	59.1	2.1	2.5	.1	59.3	-0.5	-0.2
Apr.	2.9	1	63.0	3.4	2.2	.1	65.0	-1.8	-2.0
May	.8	1	64.8	3.1	2.1	.1	70.3	-3.5	-5.5
June	9.3	1	75.1	5.3	1.8	.1	77.5	3.1	-2.4
July	10.4	1	86.5	5.7	2.6	.1	85.9	3.0	.6
Aug.	12.3	1	99.8	5.7	4.8	.1	96.5	2.7	3.3
Sept.	5.1	1	105.9	5.0	2.4	.1	104.0	-1.4	1.9
Oct.	2.3	1	109.2	3.0	2.0	.1	109.1	-1.8	.1
Nov.	.9	1	111.1	1.6	1.8	.1	112.6	-1.6	-1.5
Dec.	2.6	1	114.7	1.2	2.1	.1	116.0	.2	-1.3
Jan., 1966	4.2	1	119.9	.8	2.1	.1	119.0	2.2	.9
Feb.	4.7	1	125.6	1.1	2.3	.1	122.5	2.2	3.1
Mar.	1.3	1	127.9	1.7	2.6	.1	126.9	-2.1	1.0
Apr.	3.3	1	132.2	2.8	2.0	.1	131.8	-0.6	.4
May	4.6	1	137.8	4.5	1.9	.1	138.3	-0.9	-0.5
Total	113.8	24	137.8	77.1	59.0	2.4	138.3	-0.5	-0.5
	114	24	138	77	59	2	138	0	0

lakes, and aquifers tend to respond similarly to inflow to and outflow from the system. High and low stages occur in all at about the same time. The movement of water within the hydrologic system is reflected by changes in stage. The stages in all components in a given area fluctuate through about the same range but water stages in the eastern or upgradient areas generally fluctuate through a greater range than stages in the down-gradient, or western part.

Water levels in the western part of the area are sustained by downgradient movement of water from the east. Water levels in all streams, lakes, and aquifers do not react identically because all conveying bodies cannot transmit water equally, do not receive the same amount of recharge within a given period, nor have the same storage capabilities.

The Middle Gulf area is on the western side of the Middle Gulf hydrologic system and outflow is largely by stream discharge and evapotranspiration from the Middle Gulf area in the downgradient coastal part. Stream discharge is the residual of the inflow to the system after all the demands of nature and man's activities have been satisfied. Therefore, an increase in stream discharge from the system without an increase in inflow would result in a decrease in storage. This storage decrease would be reflected by lower stages in all components within the system. An increase in stream discharge could be brought about by lowering the discharge outlet by dredging of canals or deepening existing stream channels. The increase in stream discharge would continue until the stages in all components of the system rebalance at a lower level.

The flow of a stream is generally related to the water level in the stream; flow in a nontidal stream generally increases with an increase in water stage. The flow in tidal streams is generally greatest at low stages. Figure 42 shows that the flow of Crystal River, which is affected by tides, is less at high stage than at intermediate or low stage.

The flow of the spring-fed streams is related to the water stage in the Floridan aquifer. Figure 43 shows the relation of water stage in a well penetrating the Floridan aquifer to the flow of Weekiwachee Springs, and the relation of a shallow-aquifer and a Floridan-aquifer well to the flow of the Pithlachascotee River. The flow of Weekiwachee Springs and the water stage in the aquifer are closely related. As indicated by the scatter of points, the flow of the Pithlachascotee River is less closely related to the water stage in the aquifer than is the flow of Weekiwachee Springs.

Areally, the flow patterns of spring-fed streams throughout the Middle Gulf area are similar. The monthly mean flows of Crystal River

and Weekiwachee, Rainbow, and Silver Springs were compared to determine the relation of flow of one stream to another, figure 44. The plot of Weekiwachee-Rainbow Springs and Weekiwachee-Silver Springs indicates a constant relationship between the flows of both springs.

Changes in slope of the plots of the flow of the Crystal River-Weekiwachee Springs and the Crystal River-Rainbow Springs occur about every six months. The change in slope is caused by a flow pattern peculiar to Crystal River, because no pronounced change in slope occurred in the Weekiwachee-Silver or Weekiwachee-Rainbow plots. The change in slope of the Crystal River plots occurs at a time midway between maximum and minimum tide levels during the year.

An analysis of flow records from these streams shows that, with the exception of Crystal River, all of the spring discharges were highest in the high rainfall periods, and the lowest in low rainfall periods. The stages of the pools of Silver, Rainbow, and Weekiwachee are all 10 feet or more above sea level. The stages of the spring pools of Crystal River are near or below sea level and the discharge is influenced by tides. The discharge of Crystal River is greatest during periods of low rainfall and least during periods of high rainfall; a condition opposite to that observed in the other springfed streams and caused by the annual variation in mean tide level. These comparisons show that, with the exception of Crystal River, the pattern of flow of spring-fed streams many miles apart generally is similar and correlatable.

The mineral content of Cypress Creek, Anclote River, and Pithlachascotee River is shown in figure 45. The mineral content of the streams varies seasonally, and the range in the fluctuations of mineral content of each is similar. Both the flow and chemical composition of many streams in the Middle Gulf area show similar patterns of variation.

The stream discharge at the system boundary is essentially the residual of the inflow to the system. A change in inflow or a change in outflow upgradient from the boundary should be reflected by a change in stream discharge at the boundary.

The flow records of four streams in the southern part of the area were analysed to determine the effects on stream discharge of withdrawal of water from the Floridan aquifer. The cones of depression of well fields in northeast Pinellas and northwest Hillsborough counties extend into areas drained by several streams. The cone of the Eldridge-Wilde well field extends into an area drained by the Anclote River and Brooker Creek. The cones of the St. Petersburg Cosme, and Section 21 well fields extend into areas drained by the Anclote River and Brooker, Rocky, and Sweetwater creeks.

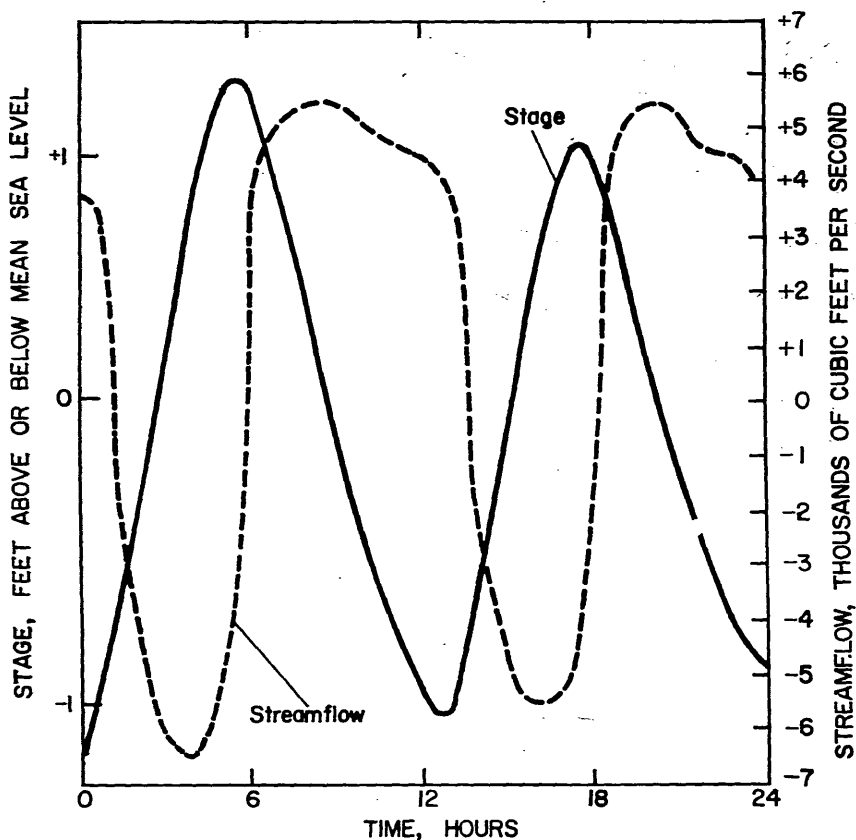


Figure 42. Graph showing relation of streamflow, stage and time in a tidal stream

The low flow characteristics of the Anclote River and Brooker Creek were analyzed to determine if they had changed as a result of pumpage of water from the Floridan aquifer. Because the low flow of Rocky Creek is affected by tides and the low flow of Sweetwater Creek is affected by regulation, the records of these two streams were not analysed.

The effect on streamflow of large withdrawals of water from the aquifer should be most evident during periods of low rainfall, because ground-water withdrawal is at a maximum, surface runoff is at a minimum, and discharge from the ground-water reservoir comprises a large part of the streamflow.

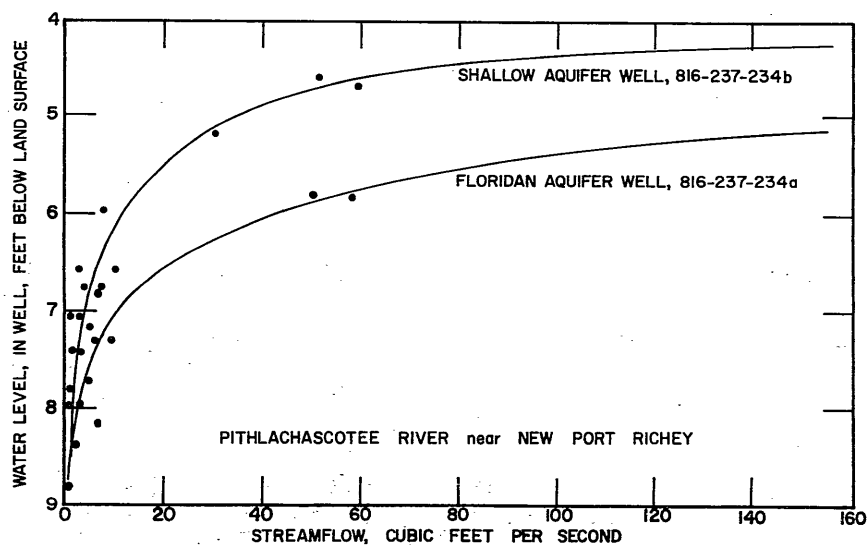
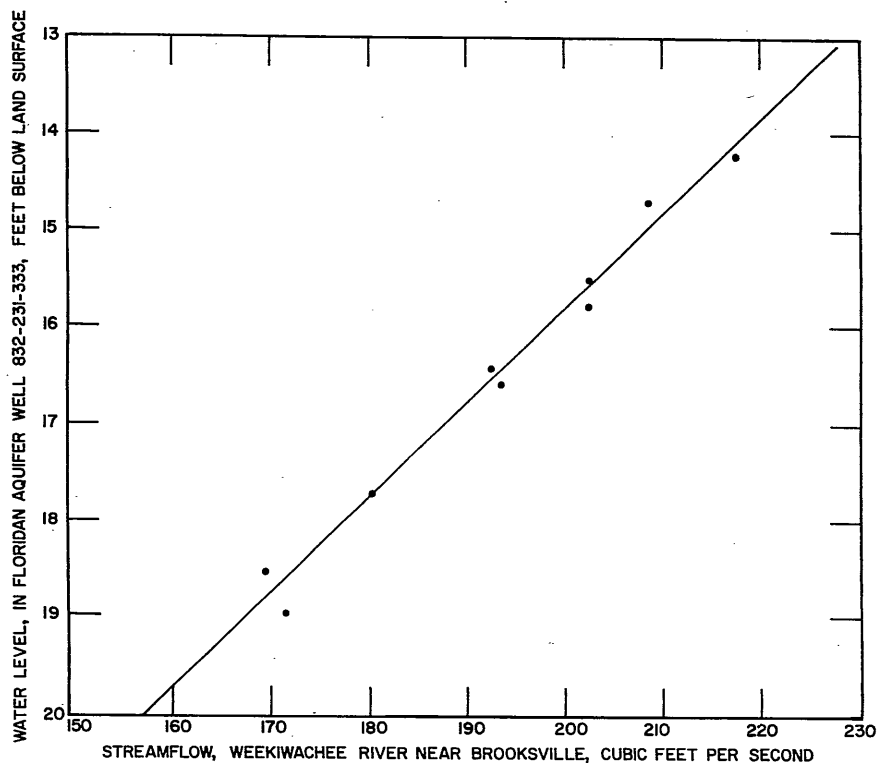


Figure 43. Graph showing relation of water level in aquifers (shallow and Floridan) to flow of streams

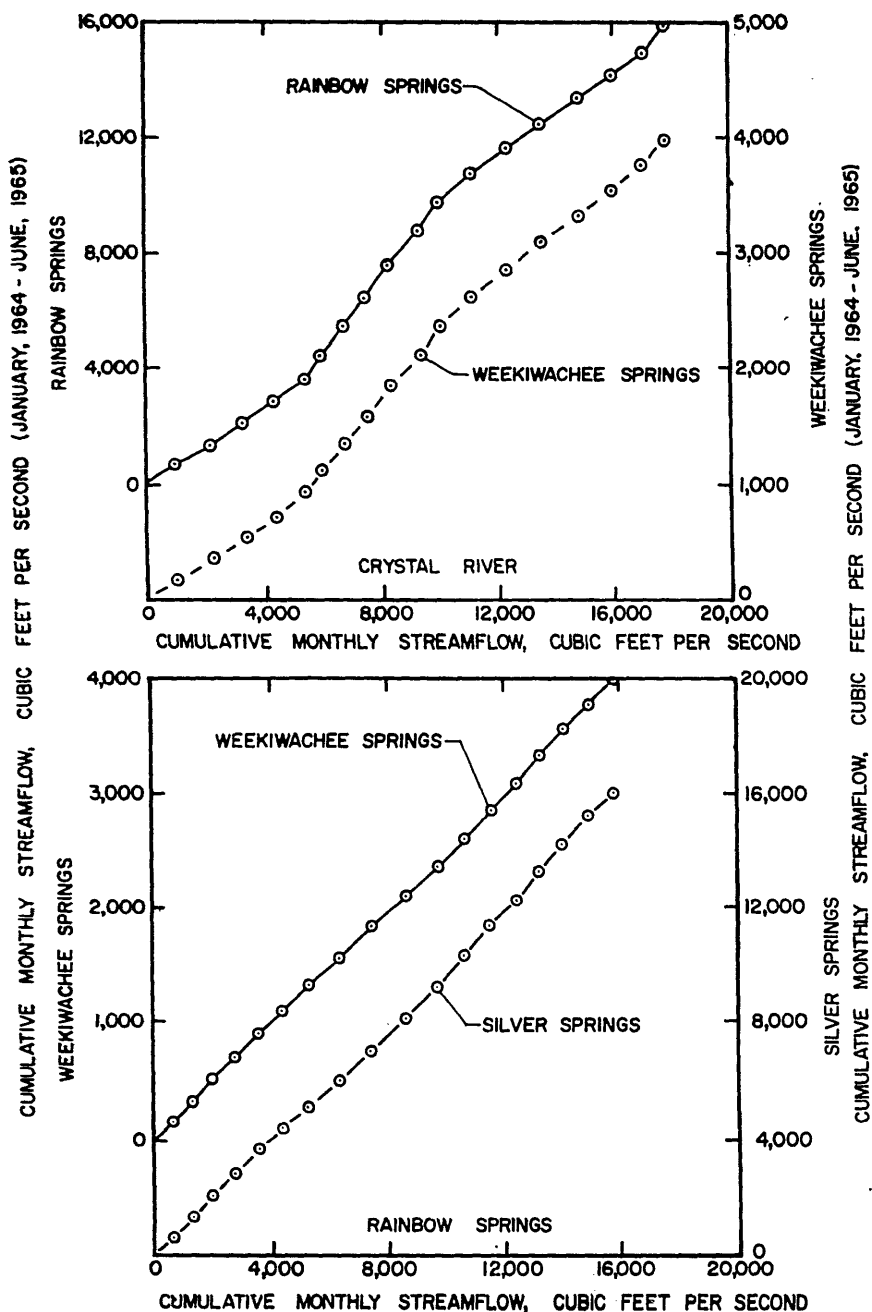


Figure 44. Graph showing Correlations of monthly mean flows of Crystal River and Weekiwachee, Rainbow and Silver springs

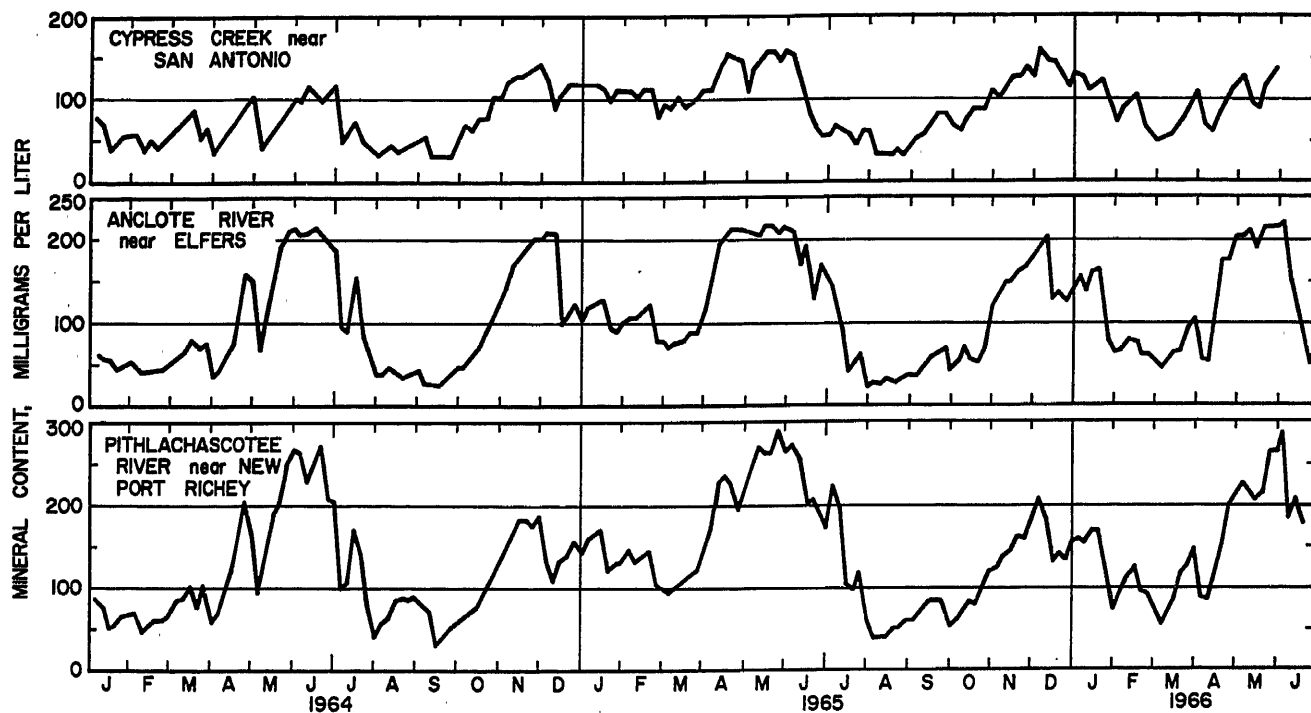


Figure 45. Graph showing similarities in seasonal changes in mineral content of water of selected streams in the Middle Gulf area, January 1964 - June 1966

An analysis of duration of low flow of Brooker Creek near Tarpon Springs was made for two periods, 1951-58 and 1959-66 (water years). This analysis compared low-flow duration curves made for periods prior to and following large ground-water withdrawals from the Floridan aquifer, which began in 1958. The average withdrawal during 1951-58 was about 13 mgd and for 1959-66, 34 mgd. The average flow of Brooker Creek near Tarpon Springs was equal to or less than 1 cfs for 671 days during 1971-58, or 23 percent of the time. During this period, the average annual rainfall was 49 inches. The average flow at this site was equal to or less than 1 cfs for 815 days during 1959-66 or 28 percent of the time. During this period, the average annual rainfall was 59 inches. Therefore, during a period of increased ground-water withdrawals and higher average rainfall, more low flow days occurred indicating that ground-water pumping did reduce the flow of the stream.

A similar analysis of low-flow duration of the Anclote River near Elfers was made for 1951-58 and 1959-66. The average flow of the Anclote River was equal to or less than 3.5 cfs (2.3 mgd) for 233 days during 1951-58 or 8.0 percent of the time. The average annual rainfall during this period was 49 inches. The average flow was equal to or less than 3.5 cfs (2.3 mgd) for 253 days during 1959-66 or 8.7 percent of the time. The average annual rainfall during this period was 59 inches. Thus, Brooker Creek and Anclote River had more low flow days during the period of high rainfall and increased ground-water withdrawals. Brooker Creek shows the greatest effect because the drainage area of the creek is almost entirely within the cones of depression of the well fields.

Similar analyses of low flows of two streams not in areas of large ground-water withdrawals, the Hillsborough River near Zephyrhills and the Withlacoochee River near Holder, show 7 percent fewer low flow days during the higher rainfall period.

WATER-RESOURCES DEVELOPMENT IN THE MIDDLE GULF AREA

The area has a large supply of good quality water available for many uses, but the increasing demands for water may, in the near future, result in accentuation of the diverse water-management problems now being experienced. They include such problems as conflict in water use, interference between well fields and resulting declines in both ground-water levels and streamflows, the lowering of some lake levels and deterioration of water quality.

The hydrologic system of the Middle Gulf area is in the down-gradient part of a larger hydrologic system which encompasses much of central Florida. Pinellas County lies within the Middle Gulf area but its water system functions essentially independently of the large Middle Gulf hydrologic system.

The long-term availability of water, that is, the amount of water that can be developed in the middle Gulf area, must take into account (a) the patterns and localities of use, (b) the quality of water in relation to use, and; (c) the changes in the hydrologic cycle brought about by the use of water. The long-term runoff plus the ground-water outflow from the area, which is about 900 billion gallons per year, or 1.5 mgd per square mile, may be considered a conservative estimate of water available from the area because:

1. It does not take into account the re-use of water.
2. It does not take into account increased recharge to the recharge to the aquifer's resulting from development of ground water, which tends to reduce evaporation and transpiration losses.

On the other hand, the runoff as represented by the streams may be considered as a maximum limit of the availability because (a) the flow of the streams cannot feasibly be totally stopped, and (b) some minimum flows must be maintained for transportation and dilution of wastes, for navigation, for recreation, and for satisfying other minimum flow requirements.

Potable water supplies in the middle Gulf area have been obtained primarily from the Floridan aquifer. In 1966, there were 18 municipal and 42 privately-owned public water supplies in the middle Gulf area. Ground-water withdrawals in the northwest Hillsborough and northeast Pinellas County well fields have increased from about 3 mgd in 1930 to about 45 mgd in 1966. The rate of increase is not expected to be constant but probably will increase at an accelerated rate as the area becomes more highly urbanized and industrialized. It can be foreseen that, before many years have passed, the coastal communities will have outgrown their average annual local water crop and will have to look for other sources, or reuse the recycled existing supplies on a vast scale. Very large quantities of brackish to saline ground water are available in the entire coastal area and at depth in the Florida aquifer inland. Such supplies can be utilized as they are now being utilized at Key West, Florida, for municipal and industrial uses. The cost of desalination would prohibit their use for large-scale irrigation under present economic conditions.

In 1966, public water suppliers pumped less than 200 mgd from the aquifer system — less than 10 percent of the manageable supply. In

areas such as northwest Hillsborough, northeast Pinellas, and southwest Pasco counties, where the rate of ground-water withdrawals are greatest, no extensive overdevelopment and depletion of supply was evident. Stewart (1968) has shown that pumping of water from the Floridan aquifer in these areas has contributed to local declines in water levels in the aquifers and in some lakes.

Low lake levels have occurred in the well-field areas in northwest Hillsborough and northeast Pinellas counties. Low lake levels occur mostly during the spring months owing to a combination of conditions which include low rainfall, high evapotranspiration, and increased withdrawals of ground water because of irrigation demands.

Salt-water encroachment has occurred in the coastal areas and is most extensive in the Pinellas County area. According to Black (1953), "the former supply of the city of St. Petersburg was from local artesian wells. The steadily increasing withdrawal of fresh water from the formations permitted the entrance of salt water to such an extent that serious damage has been done throughout the area." *** "In 1929 the present Cosme-Odesa well field was located 37 miles away in NW Hillsborough County in order to get away from salt water intrusion".

Because of the interrelation of surface and ground water in the area, the following are alternatives or factors to be considered in selecting prospective well-field sites:

1. Well fields should be located inland from the coast to minimize danger of salt-water intrusion into aquifers;
2. Well fields in well-drained areas should be located at maximum distances from lakes and other wells and well fields to eliminate or minimize possible effects of pumping on lake levels and interference between individual wells and well fields. In areas where lakes have esthetic value, new well fields would need to be located as far away as is feasible. However, because of the large number of lakes, pumpage at any site doubtless will affect the levels of some lakes. By keeping the distance between individual wells, well fields and lakes at a maximum, the effects of pumping may be such that the amount of water lost by vertical leakage from lakes is negligible in comparison to the seasonal change in the lake levels caused by natural climatological factors;
3. Locating well fields in poorly drained areas, or in areas where lakes have little esthetic value will tend to reduce evapotranspiration by lowering the water surface. This should increase the net usable water supply and concurrently drain the land;

4. Locating wells near streams to reduce natural discharge of ground water by inducing flow from the stream into the aquifer.

Locations potentially favorable for the development of additional ground water are the northern and northeastern parts of the area inland from the coast where interference from well fields in the southern part of the area would be minimized. Most of this area is sparsely populated and pumpage is limited to a few domestic, stock, and irrigation wells. Although no wells are known to have been test-pumped in these areas, it is expected that the Floridan aquifer will yield adequate water for increased municipal supplies. Before any large-scale development is undertaken in the area, test wells should be drilled to define specifically the hydraulic properties of the aquifer, and to define anticipated well yields as accurately as possible. Such information will also be needed to determine the effects of pumping on nearby lakes and streams, and to ascertain the needed spacing of wells that will minimize interference between wells or between well fields.

Studies of selected areas having significant declines in ground-water and lake levels would allow determination of the feasibility of artificially recharging the Floridan aquifer by diversion of surface water during maximum and medium flow periods. If such studies are made, several methods of recharging the aquifer should be tested, including (a) routing of water into lakes, ponds, and other depressions; (b) discharge of water into sinkholes, recharge canals and pits; (c) injection of water into recharge wells, and (d) a combination of the above methods.

The rapidly expanding urban population will result in a reduction in local recharge to the aquifer in parts of the area and at the same time will increase the hazards of changes in water quality in other parts of the area.

The resource cannot be considered inexhaustible. It is subject to overdevelopment and to deterioration in quality by uncoordinated, competitive and conflicting demands. Continued development will modify and complicate the water system. Current programs of data collection and interpretive studies should be included as part of a sound planning and management program for the area. Optimum successful development and management of the resource will require cooperation and support of all water users.

SUMMARY

The Middle Gulf area is on the western side of a large hydrologic system which encompasses most of west-central Florida. Water enters

the hydrologic system as precipitation and moves westward through the Middle Gulf area to the Gulf of Mexico.

The area is underlain by a thick limestone and dolomite sequence, the upper part of which is the Floridan aquifer. This aquifer supplies nearly all the ground water used in the area. Streams and evapotranspiration discharge most of the water from the area. Water in the streams is chiefly discharged from the Floridan aquifer. The principal streams are Crystal, Homosassa, Chassahowitzka, Weekiwachee, Pithlachascotee, and Anclote Rivers and Rocky, Sweetwater, and Cypress Creeks. The largest stream, Crystal River, discharged an average of 930 cfs (600 mgd) for the 2-year period.

The water balance (in inches) for the Middle Gulf area for the period June 1964 — May 1966 is:

$$\begin{aligned}\pm \Delta S &= GI + P - ET - R - GO \\ O &= 24 + 114 - 77 - 59 - 2\end{aligned}$$

This equation shows that no change in storage (ΔS) occurred during the balance period and inflow to the Middle Gulf area was precipitation (P) and ground-water inflow (GI). The outflow from the area was primarily evapotranspiration (ET) and streamflow (R). Ground-water outflow (GO) was small.

Although evapotranspiration is highest during the summer, precipitation greatly exceeds the evapotranspiration, and water stages and storage in all water-conveying components are highest during the summer.

The principal water-conveying component in the Middle Gulf area is the Florida aquifer. The average flow through the aquifer is estimated to be 2,800 cfs (1,810 mgd) for the period of study. Most of this flow occurred in the northern part. The transmissivity of the aquifer is estimated to range from about 100,000 gpd per ft in the southern part to more 10 million gpd per ft in the northern part. The top of the aquifer ranges from about 80 feet above msl in the eastern part to more than 60 feet below msl in the southern part near the coast.

The water level in the Floridan aquifer ranges from more than 90 feet above msl in the eastern part to sea level at or near the coast. The water-level gradient in the aquifer averages about 3 to 5 feet per mile, or about the same as the slope of the land surface. Water in the aquifer is confined in parts of the area and unconfined in other parts. Recharge to the aquifer occurs over most of the Middle Gulf area, in part by vertical leakage through the overlying sediments and through sinkholes and by ground-water inflow from adjacent areas. Discharge from the aquifer is

primarily through springs and seeps into streams but some discharge takes place by seepage into the Gulf of Mexico. Seasonal water-level fluctuations in the aquifer range from about 3 to 5 feet. No regional decline in water levels was noted. The decline of water levels in areas of heavy pumpage in northwest Hillsborough and northeast Pinellas counties ranged from about 6 to 14 feet during the period 1958 — 65. Ground-water withdrawals in the well-field areas increased from about 3 mgd in 1930 to about 45 mgd in 1966.

Lakes are more numerous in the southern part than in the northern part of the Middle Gulf area. The stages of some lakes fluctuate as much as 5 feet per year, whereas in other lakes fluctuations are only about 3 feet per year. In general, lakes in upgradient areas and in the well fields in the southern part of the area have the greatest range of fluctuation.

Ample supplies of good quality water are available for existing and foreseeable uses. The present (1969) problem is one of water management and optimum development rather than availability of water. By properly spacing wells, avoiding excessive pumping rates, and distributing well fields, drawdowns between wells and between respective well fields can be minimized and overdevelopment and subsequent declines in water levels, now reflected to some degree in lowering of lake levels locally and reduction in streamflow also would be minimized. A reduction in the decline of water levels as a result of pumping would minimize conflicts of interest between various water users throughout the area. Eventually, however, if the population continues to grow and if industrialization grows apace with the urbanization, the time will come when local fresh-water supplies will not be available on an annual average basis in quantities needed. In other words, man's demand will exceed nature's annual replenishment of the resource, making reuse of water, recharge of the aquifer with flood water, and other means of augmenting the available supply necessary if the needs are to be fully met.

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